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ANGIOGRAPHIC STUDIES OF THE ANATOMY OF SINGLE AND MULTIPLE RENAL ARTERIES

by

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INTRODUCTION

Renal angiography, the performance of the examination and assessment of the findings, requires a thorough and detailed knowledge of the renal arteries and of their normal range of variation. The anatomy of the renal arteries has previously been studied mainly by classical anatomic methods in autopsy specimens. The pattern of the intrarenal primary and secondary branches and of the supplementary arteries has not been related to modern concepts of the internal topography of the kidney.

In the present investigation, which is based on clinical material from the Roentgen diagnostic Department of the University Hospital, Lund, renal angiography is used to study the anatomy *in situ*. This will broaden the basis of the classical anatomy and convert it into clinical anatomy. The investigation is concerned with the course and distribution of single and multiple renal arteries and their branches and of branches supplying adjacent renal structures.

PART I

A SINGLE RENAL ARTERY

INTRODUCTION

About 70 % of all kidneys are supplied by a single renal artery. This part of the investigation is concerned with the following features of the renal artery: (a) course from the aorta to the renal hilum, (b) ramification, and (c) origin, course and segmental distribution of its branches which are anatomic characteristics of importance to the technical and diagnostic aspects of renal angiography.

The level of origin of the renal artery is anatomically (HELM 1896, HEIDSIECK 1928, TANIGUCHI 1931) and angiographically (EDSMAN 1957) clear: the artery arises from the aorta at the level of the lower third of L I with a variation of about one vertebral body in a cranial or caudal direction. In the present material all of the renal arteries originated at a level described by EDSMAN (1957) as normal.

EARLIER INVESTIGATIONS

COURSE OF THE RENAL ARTERY FROM AORTA TO RENAL HILUM

A thorough search of the literature revealed only scanty anatomic studies and no angiographic investigations. The course is often described as transverse or horizontal (ALGIER 1923, RAUBER-KOPSCH 1941 and others), descending (ALGIER 1923, HOU-JENSEN 1930, NARATH 1951 and others) or, in rare cases (GREIG SMITH 1888, ALGIER 1923) as ascending.

RAMIFICATION AND ORIGIN, COURSE AND SEGMENTAL DISTRIBUTION OF THE BRANCHES OF THE RENAL ARTERY

The main branches given off by the renal artery are usually described according to their origin from the proximal, medial, or distal third of the renal artery on its passage from the aorta to the renal hilum. Cases in which the artery does not divide until it reaches the ... us of the kidney are usually assigned to the last mention... 11, HOU-JENSEN 1930)
SCH... segmental arteries in 35 %

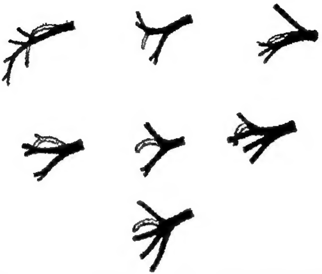


Fig 1 Variation in origin of dorsal artery from renal artery (after ALBARRAN & PAPIN 1908)

of 80 kidneys and bifurcation in the sinus of the kidney in 6 % GÉRARD (1911) examined 207 kidneys and found a proximal origin in 18 % a medial in 14 % and a distal or sinus origin in 68 % HOU-JENSEN (1930) found similar figures for 60 kidneys but PALUMBO (1952) found in 34 kidneys a proximal origin in 6 % medial in 12 % and a distal or sinus bifurcation in 82 %

The branches of the renal artery have been described according to their field of supply as polar ventral and dorsal The ventral and dorsal arteries have also been described in relation to the kidney pelvis

The *dorsal artery* is usually given off before the renal artery enters the hilum but in rare cases it may branch from a ventral artery in the sinus (ALBARRAN & PAPIN 1908 HOU-JENSEN 1930 MERKLIN & MICHELS 1958) (Fig 1) The dorsal artery seldom divides before reaching the hilum It enters the upper part of the sinus either cranial dorsal or caudal to the ventral artery (PALUMBO 1952) The vessel then runs cranial to the confluence of the kidney pelvis or immediately dorsal to its upper part after which it describes an arc with the convexity facing craniolaterally As a rule the dorsal artery first runs horizontally into the sinus but then bends in caudal direction after which it often runs parallel to the dorsal hilar lip (ALBARRAN & PAPIN 1908 HELLSTRÖM 1928 HOU-JENSEN 1930 GRAVES 1954 and others)

(Fig 2) When the vessel descends in caudal direction it often crosses the upper calyx (GRAVES 1954) Branches are given off from the convex aspect and run to the dorsal part of the kidney

Opinions differ on the field of supply of the dorsal artery GREGOIRE (1906) was the first to trace the pattern of the arteries from their entry into the hilum and their field of supply in the parenchyma He claimed the existence of a separate artery for the dorsal and the ventral halves excluding the poles, each of which was supplied by a separate artery The artery supplying the upper pole, however stemmed from the dorsal artery Other authors (ZONDEK 1903, ALBARRAN & PAPIN 1908) expressed the view that the dorsal artery supplied not only the center of the dorsal part of the kidney, but also the dorsal part of the upper pole, while BRODEL (1901) believed that the ventral artery supplied the pars superior GRAVES (1954) found that the dorsal artery nourished the dorsal half of the kidney with the exception of the most apical part and of the pars inferior

The ventral artery is, as a rule much greater in caliber than the dorsal artery and they are seldom of equal width (BRODEL 1901, ZONDEK 1903 ALBARRAN & PAPIN 1908 and others) As a rule, the artery arborizes into three or four branches immediately before or within the hilum These branches usually enter the upper part of the hilum cranial to the confluence of the kidney pelvis, whence they spread radially in the sinus over the ventral side of the confluence (ALBARRAN & PAPIN 1908, GÉRARD 1912, HOU JENSEN 1930, MERKLIN & MICHELS 1958) The ventral arteries branch further in the sinus and follow the calyces to the level of the papillae, after which they enter the columnae Bertini as interlobar arteries The central branches of the ventral artery supply the middle of the kidney (ALBARRAN & PAPIN 1908, GÉRARD 1912) PRIWES (1935) claimed that an artery, which he designated *a centralis, usually supplied the ventral middle part of the kidney* BELLOCQ (1914) showed that the lower pole was supplied by branches of the ventral artery, while other investigators (BRODEL 1901, GRAVES 1954 and others) claimed that the upper renal pole was also supplied by the ventral artery

GRAVES (1954) who divided the kidney into 5 segments, was able to show that the ventral artery usually supplied 4 segments (Fig 3), which he called apical, upper, middle and lower segments The last three were regularly supplied by the ventral artery, while the nutrition of the apical segment (representing the upper medial part of the kidney) varied The peripheral arterial branches were dependent, to a certain extent, on the topography of the calyces (PRIWES 1935, GRAVES 1954)

GRAVES reported that the arterial supply of the middle segment of the kidney arises as a branch from the artery to the upper segment in 53 3 % of

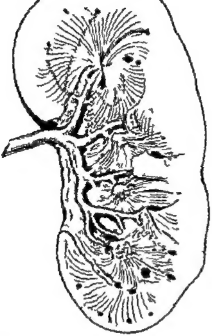


Fig. 7. Course and ramification of dorsal artery in situ (after HOU-JENSEN, 1930)

kidneys, in 30 % from the artery to the lower segment, and in 16.6 % from the same location as the two arteries to the upper and lower segments.

Polar arteries. — As mentioned, opinions differ on the arterial supply to the *upper pole*. This disagreement is due mainly to the inexact definition of the boundaries of the upper pole of the kidney. It may be said that the upper pole is supplied by both ventral and dorsal arteries. According to GRAVES the medial upper part of the pole is supplied by branches of the ventral artery in 43.3 % of kidneys, in 23.3 % of kidneys by a branch originating at the bifurcation of the ventral and dorsal arteries, by a branch proximal to the bifurcation in 23.3 %, or by branches from the dorsal artery in 10 % of kidneys. The remaining part of the upper pole is supplied by branches running cranially from the ventral and dorsal arteries. CHIAUDANO (1955) would not accept the name polar arteries on the grounds that there were no upper and lower polar regions of supply to be recognized. He admitted that arteries occasionally

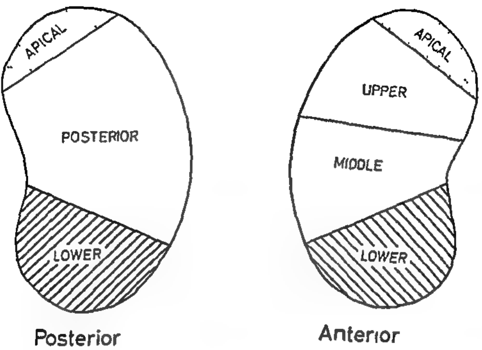


Fig 3 Diagram of right kidney showing the five arterial segments. The apical and lower segments occupy the ventral as well as the dorsal halves of the kidney (after GRAVES 1954)

ran to the poles but that they were not so common as to justify classification as normal variants

It is widely agreed that the *lower renal pole* is supplied by a ventral artery dividing at the level of the lower calyx into a ventral and a dorsal branch (BRODEL 1901 GRÉGOIRE 1906 BELLOCQ 1914 GRAVES 1954) HOU JENSEN (1930) confirmed this fact in 23 of 30 kidneys but in the remainder the lower pole was divided into a ventral and a dorsal part the latter being supplied by a branch of the dorsal artery

The various secondary branches which thus supply different segments in the kidney give off the interlobar arteries These arteries enter the parenchyma between two pyramids and usually supply adjacent parts of the latter The segmental artery with its interlobar arteries can however supply only one pyramid (SCHMERBER 1895 GERARD 1912 HOU JENSEN 1930) At the bases of the pyramids the vessels bend to form the arcuate arteries and give off the interlobular arteries to the cortex The interlobular arteries are readily de

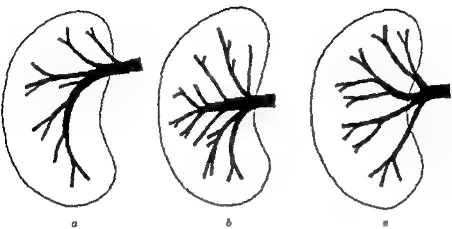


Fig. 4. Diagram of variation in course and ramification of renal artery. *a* Typus magistralis I. *b* Typus magistralis II. *c* Typus dispersatus (modified after KUPRIJANOFF 1924)

monstrated in angiograms of operative or post mortem specimens but they cannot be followed angiographically *in vivo*.

HYRTL (1872), who used corrosion preparations, was the first to show that the ventral and dorsal arteries were end arteries supplying their own separate areas of the kidney. This has since been verified by many in autopsy studies (BRÖDEL 1901, ALBARRAN & PAPIN 1908, HOU-JENSEN 1930, PICK & ANSON 1940, NARATH 1951, GRAVES 1954, SMITHUIS 1956 and others) and at operation (HELLSTRÖM 1928, BERGENDAL 1936 and others) and by renal angiograms (EDSMAN 1957 and others).

By demonstrating the independent nutrition of the ventral and dorsal parenchyma of the kidney HYRTL (1872) presented his thesis on the "natürliche Teilbarkeit" of the kidney. Like BRÖDEL (1901) he believed these vascular regions to be completely separate from one another. HOU-JENSEN (1930), FUCHS (1931) and LÖFGREN (1949), however, found that the ventral parenchymal arteries were sometimes demonstrable among the dorsal and that there was thus no avascular zone between the two fields of supply.

BRÖDEL (1901), HOU-JENSEN (1930), LÖFGREN (1949) and CHIAUDANO (19[illegible]5) found the field of supply of the ventral artery to be larger in that the vessel also supplied the ventral parts of the dorsal pyramids. ZONDEK (1903) arrived at the same conclusion; he found that the border between the fields of the dorsal and ventral arteries was 0.5—1.[illegible] cm posterior to the lateral

border of the kidney LOFGREN (1949) found that the shape of the hilum indicated which part of the kidney was the least vascularised, the part under consideration being situated dorsally to the spatium longitudinale

KUPRIJANOFF (1924) who injected contrast medium into the renal pelvis and arteries charted the ramification of the latter but did not make any distinction between ventral and dorsal arteries On the basis of his investigations he divided the vascular tree into two main types (Fig 4) magistralis and dispersatus

A *Typus magistralis* — The main artery enters undivided into the hilum Of this type there are two variants first (Type I) in which the main artery enters the upper part of the hilum after which it runs parallel to the lateral surface of the kidney and gives off branches on its way NARATH (1951) therefore called this type of vessel Typus magistralis longitudinalis Secondly (Type II) the renal artery enters the middle of the hilum and then continues at right angles to the longitudinal axis of the kidney giving off radial branches on its way NARATH (1951) called this form Typus magistralis transversalis

B *Typus dispersatus* — The main artery divides before it reaches the hilum KUPRIJANOFF found this type in about 35 % of cases The magistral type was seen in 65 % of which Type I was seen in somewhat more than two thirds

He described the dispersed type as being more common in the presence of extrarenal pelvis or kidney lobulation and claimed that it represented a lower state of development than the magistral Intermediary forms were seen by KUPRIJANOFF in about 1 %

PRIWES (1935) was unable to confirm KUPRIJANOFF's findings in every respect but found the dispersed type in kidneys with ampullary renal pelvis, while the pelvis was better developed in kidneys of the magistral type Apart from the observation that the peripheral arborization of the vessels was to a certain extent dependent on the number of calyces, in man he was unable to demonstrate any definite relationship between the shape of the renal pelvis and the arborization of the artery In animals, however, he often found the vascular pattern to vary with the shape of the renal pelvis

CHIAUDANO (1955) studied extirpated kidneys angiographically He found the arteries to break up mainly into 2 groups namely branches running parallel to the sinus and branches running at right angles to the sinus Apart from this he could find no systematic tendency of the arborization of the vessels SMITHUIS (1956) found essentially the same pattern

SUMMARY

Extensive investigations by various authors have demonstrated varied courses of the renal artery to the kidney and of the ramification through the sinus Different opinions are on record regarding the regions supplied by branches of the renal artery GRAVES (1954) was the first to describe a segmental arrangement of the areas supplied by the renal artery In clinical renal angiograms the course of the renal artery its ramification and the segmental arrangement of the kidney area supplied have not been investigated

AUTHOR'S INVESTIGATIONS

From a roentgen diagnostic point of view, knowledge of the segmental distribution of the various branches of the renal artery is of particular importance. Graves, as mentioned, appears to be the only investigator to have described the vascular pattern in relation to the various parts of the renal parenchyma which he divided into 5 segments. His studies are based on specimens removed *post mortem* and cannot be applied directly to renal angiography because of the position of the kidney *in vivo*. Neither were they based on the topographical arrangement of the pyramidal system, which is the determining factor for the form of the kidney.

Since primary and secondary branches divide into interlobar arteries running in the columnae Bertini it might appear logical to describe the pattern of such branches in relation to the position of the pyramids. The description of the *distribution of the arteries is based on the fundamental investigation of the* topographic arrangement of the pyramids by Lofgren (1949).

The arterial branches supplying the pyramids also supply enclosing cortical substance so that description of the distribution of the branches among the pyramids will in reality be a description of the branches to the renculi.

NOMENCLATURE

Lofgren recognized three parts of the kidney, namely pars superior, pars intermedia and pars inferior (Fig. 5), the last two parts together forming the lobus primordialis inferior. Between these three parts grooves, called [illegible] interpartialis superior and inferior, are seen in more than 80 % of all kidneys in adults. These sulci radiate slightly from the lateral upper and lower [illegible] angle, and the pars intermedia lies between these two.

The kidney is made up of 7 pairs of pyramids, each pair consist[illegible] ventral (V) and a dorsal (D) pyramid (pyr.). Three pairs are situated [illegible] the pars superior (hereinafter referred to as pyr. 1–3 V D), 2 in pars [illegible] (pyr. 4–5 V D) and 2 in pars inferior (pyr. 6–7 V D) (Fig. 5). The pyra[illegible] considerably in shape and size, especially in the pars superior and [illegible]

but their positions in the kidney are fairly regular The pyramids in the pars intermedia may be angular because of the shape of the hilum Thus if the hilum is on the dorsal side the lateral parts of pyr 4–5 D will bend ventrally so that the lateral part of the bases of the pyramids will form part of the ventral surface of the kidney

Renal angiography will as a rule demonstrate the topography of the renal vessels A thorough study of the nephrogram has shown that it is possible in most cases to observe the above mentioned sulci and the hilum The sulci appear as faint indentations on the lateral surface of the kidney At the end of the arterial phase and early in the nephrographic phase accumulation of contrast medium is seen in the cortex and columnae Bertini permitting distinction of the different pyramids (Fig 6) The dorsal and ventral pyramids of each pair are essentially on the same cranio caudal level but do not completely coincide antero posteriorly because of some latero medial displacement

The fields of supply of the various arteries were studied on the basis of the above topographic data No generally accepted nomenclature is available for the primary and secondary branches of the renal artery The essential point of any name used is that it clearly indicates the field of supply and its relation to the renal pelvis The renal artery is called a renalis until the departure of the dorsal artery (a dors) after which it is termed the ventral artery (a ventr) These 2 main branches are *primary branches* and course dorsal and ventral to the kidney pelvis Further primary branches are also given off to different parts of the kidney most frequently to the poles (r sup or r inf) before the departure of the dorsal artery or together with the latter to form a tri or quadrifurcation In an attempt better to define the area of supply of the primary branches the pyramid numbers are also given as well as the letter V or D to denote whether the pyramids are located in the ventral or dorsal part of the kidney There are thus 4 types of primary branches They may be defined in the following way (Fig 7a)

renal artery
- r sup pyr 1–2 V D
- a dors pyr 3–6 D
- a ventr pyr 3–5 V
- r inf pyr 6–7 V 7 D

The dorsal and ventral primary branches give off *secondary branches* (r dors and r ventr) If the arteries to the renal poles arise from the dorsal or ventral arteries they are secondary branches All of the secondary branches are *segmental arteries* (or subsegmental arteries) since they only supply certain limited parts of the renal parenchyma If the segmental arteries stem from ventral or dorsal arteries the vasculature may be defined as follows (Fig 7b)

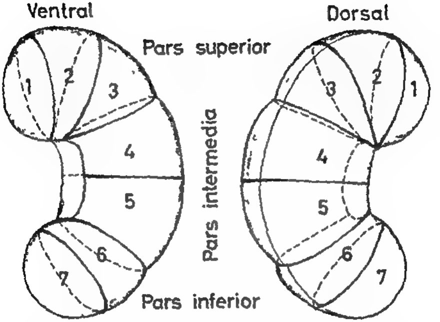


Fig. 5. Diagram of topography of left kidney based on the studies performed by LÖFGREN (1949). Numbers 1–7 indicate surfaces corresponding to the ventral and dorsal pyramids.

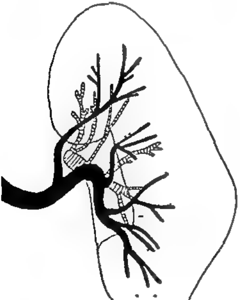
	Primary arteries	Seg. or (sub)segmental arteries
renal artery	a. dors. pyr. 1–2 V, 1–5 D	rr. dors. pyr. 1–2 V D
		r. dors. pyr. 3–4 D
		r. dors. pyr. 5 D
	a. ventr. pyr. 3–7 V, 6–7 D	r. ventr. pyr. 3–4 V
		r. ventr. pyr. 5 V
		r. ventr. pyr. 6–7 V D

Segmental arteries are further divided into *subsegmental arteries* which supply portions of a segment, *e.g.* r. dors. pyr. 5 D. These subsegmental arteries also branch directly from the primary arteries or from the renal artery.

The *interlobar arteries* depart from the subsegmental arteries in the sinus and enter the parenchyma between 2 pyramids. The number varies, but as a rule there are sufficient for each pyramid to be supplied by a subsegmental artery. As the pyramids represent the basic segments of the kidney, there is a segmental supply, but each interlobar artery usually gives off branches to 2 adjacent pyramids. The division of the segments can therefore not be

a

b



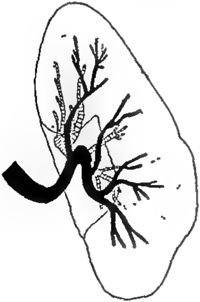
c

F g 6a–c Select ve rer al ang ogram (left k lney) Frontal view The f rm ila of ar ter al tree is

[a rer alis] — r sup pyr 1 3 V
— a d rs pyr 1 5 D
— a ventr pyr 4 7 V 6–7 D

d

f



e

Fig 6d–f Oblique view Because of the projection the dorsal artery appears more medially than in frontal view In the nephrogram accumulation of contrast in cortex and columnae Bertini outline the pyramids as well as the hilum

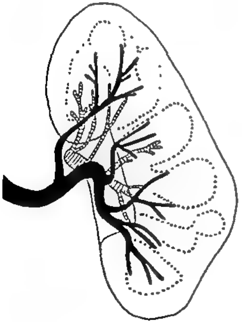
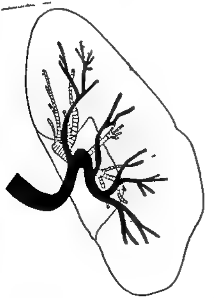


Fig. 6a–c. Selective renal angiogram (left kidney). Frontal view. The formula of arterial tree is

a. renalis
- r. sup. pyr. 1–3 V
- a. dors. pyr. 1–5 D
- a. ventr. pyr. 4–7 V, 6–7 D

d

f



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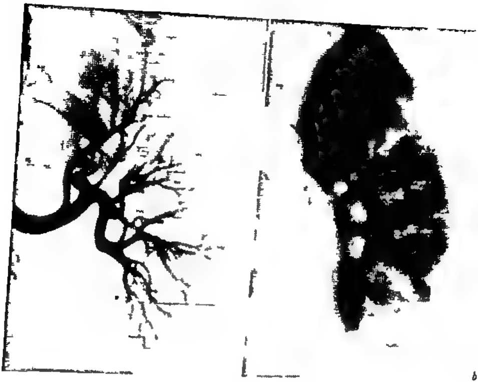

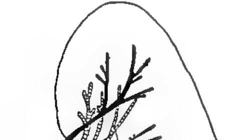

Fig. 6a–c. Selective renal angiogram (left kidney). Frontal view. The formula of arterial tree is

a. renalis — a. sup. pyr. 1–3 V
a. renalis — a. dors. pyr. 1–5 D
a. renalis — a. ventr. pyr. 4–7 V, 6–7 D

d

f

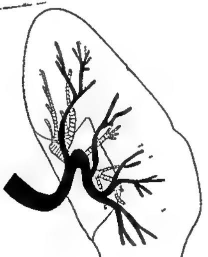

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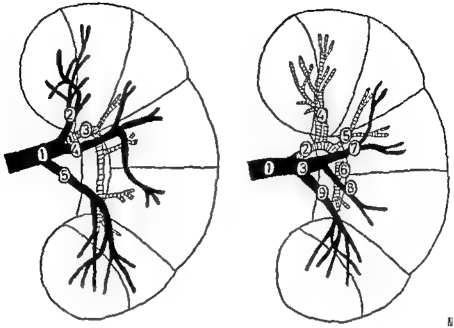
Fig 6d f Oblique view Because of the projection the dorsal artery appears more medially than in frontal view In the nephrogram accumulation of contrast in cortex and columnae Bertini outline the pyramids as well as the hilum



a *b*

Fig 7 Diagram of left kidney showing nomenclature of different segmental arteries in formula below

a (1) a renalis
- (2) r sup pyr 1 2 V D
- (3) a dors pyr 3 6 D
- (4) a ventr pyr 3 5 V
- (5) r inf pyr 6 7 V, 7 D

b (1) a renalis
- (2) a dors pyr 1 2 V 1 5 D
  - (4) rr dors pyr 1–2 V D
  - (5) r dors pyr 3 4 D
  - (6) r dors pyr 5 D
- (3) a ventr pyr 3 7 V 6–7 D
  - (7) r ventr pyr 3–4 V
  - (8) r ventr pyr 5 V
  - (9) r ventr pyr 6–7 V D

exact On the other hand, the secondary branches usually supply more than one pyramid permitting division of the kidney into greater segments and then the poor definition due to the interlobar arteries will be of less importance

MATERIAL AND METHODS

AUTOPSY MATERIAL

Twenty three kidneys, each with a single renal artery, were studied regarding the regions supplied by the arteries

The kidneys were removed together with the renal capsule and the aorta, the latter being slit up from the ventral side in order to check that the kidney was supplied by a single artery. A suspension of colloidal $BaSO_4$ (Collobar, Astra) was injected into the renal artery, which was ligated at its origin. The arterial vasculature was then studied in three different projections: (1) the kidney lying flat on the support (true frontal projection); (2) with the kidney tilted about 45° so as to obtain an image corresponding to that obtained in a frontal view *in vivo*; (3) with the kidney rotated so that the dorsal surface faced medially, i.e. a view corresponding to a true lateral projection (Fig. 8). The contrast medium (Collobar suspension or 50 % Umbradil) was then injected into the renal pelvis and the 3 above mentioned projections were repeated.

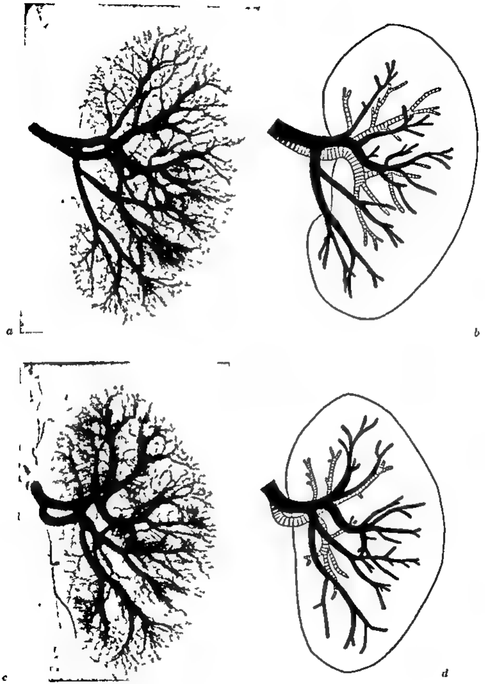
CLINICAL MATERIAL

Thirty-three kidneys (10 right, 23 left) were examined in two projections by selective angiography according to the method of ÖDMAN (1956). Frontal films were taken with the patient in the supine position (corresponding to projection 2 above) and oblique films with the patient tilted to the side to be studied (projection 3 above). In some cases lateral films were taken instead of oblique. In these projections it is possible to distinguish between dorsal and ventral arteries (WEYDE 1954, FRIMANN-DAHL 1958). Selective angiograms also permit evaluation of the columnae Bertini and the outline of the hilum, and can therefore be used with advantage in the investigation of the renal arteries *in vivo*.

The findings from these renal angiograms were then compared with the data obtained from the autopsy studies.

It was soon realized that the frontal films alone were sufficient to decide which of the arteries were dorsal, the arteria dorsalis being of characteristic course and appearance (Figs. 2—8): *a*. The dorsal artery was often found to arise as the first branch from the renal artery (which distal to that point was called the ventral artery). *b*. Its caliber was, as a rule, smaller than that of the ventral artery. *c*. It coursed in the sinus in a typical way with the descending part often running vertical and parallel to the posterior hilar lip. *d*. Its branches crossed characteristic vessels of the ventral artery. *e*. Owing to the position of the kidney *in vivo* between the frontal and sagittal plane the field of supply of the dorsal artery was located more medial than that of the ventral artery. In the pars intermedia the peripheral branches of the ventral artery always extended out to the lateral part of the kidney, but never those of the dorsal artery, provided the kidney was not malrotated. Thus the material could be extended to include examinations of other patients, of whom films had been taken in only one plane. A further 100 kidneys (51 right, 49 left) were therefore studied with regard to the region of supply of the segmental arteries.

Origin, course and segmental distribution of the branches of the renal


a
b
c
d

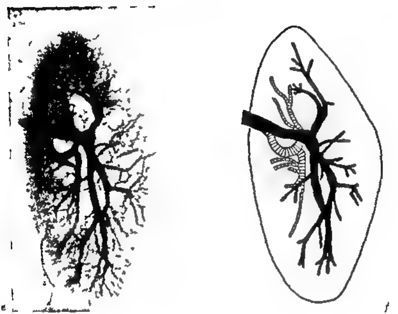


Fig 8 Autopsy specimen (left kidney) examined in three projections

a–b True frontal projection with kidney flat on examination table Branches of dorsal artery do not cross one another neither do those of ventral artery except in lower pole The course of dorsal artery is characteristic

c–d View comparable to frontal projection *in situ* Dorsal artery and its branches appear more medially in this semi lateral view

e f True lateral projection i e view comparable to oblique projection *in situ*

artery were thus studied in 156 kidneys with a single renal artery which were accounted for above namely 23 removed *post mortem* 33 examined by selective renal angiography in two planes and 100 kidneys of which renal angiograms had been taken only in one plane An attempt to divide the supply of the kidney into the previously mentioned parts (pyr 1 3 V D pyr 4–5 V D pyr 6 7 V D) confirmed the findings by SMITHUIS (1956) that they did not coincide with the fields of supply of the segmental arteries For example the subsegmental artery to pyr 3 V which belongs to the pars superior often encroached upon parts of pyr 4 V which belongs to the pars intermedia and the artery to pyr 5 V often supplied the cranial portion of pyr 6 V The arteries to the intermediate ventral and dorsal segments had one characteristic in common

Table 1 Course of renal artery from aorta to renal hilum (clin cal ang ographic material)

S de	Ascending		Horizontal			Descen ling			Total
	Num ber	Per cent	Num ber	Per cent	Of wh ch ptosis	Num ber	Per cent	Of which ptosis	
Right	14	8 6	64	39 5		84	51 9	23	162
Left	61	40 1	66	43 4	2	25	16 5	9	152
Total	75	23 9	130	41 4	2	109	34 7	32	314

RESULTS

COURSE OF THE RENAL ARTERY FROM AORTA TO RENAL HILUM

All of the angiograms were taken during the expiratory phase with the patient supine In the classification of the course of the renal artery three types were recognized namely ascending horizontal and descending In young persons the renal artery runs a fairly straight course to the kidney Most of the subjects in the present material however consisted of elderly persons Though the aorta in such age groups may be of normal appearance the renal artery may be of larger caliber and more tortuous than in younger people The course of the renal artery was judged simply by the relationship between the origin from the aorta and the level of its entry into the hilum

A total of 314 kidneys (162 right 152 left) were examined in this way and the results are given in Table 1

In about 10 per cent of the kidneys renal ptosis was observed mainly on the right side Here a kidney affected with ptosis is to be understood as one [illegible] kidney is abnormally low the renal artery runs a fairly straight caudal course and subtends a small acute angle with the aorta In these cases the vessel is distinctly elongated (Fig 10)

RAMIFICATION OF THE RENAL ARTERY

The first division of the renal artery may occur in the proximal middle or distal third or even in the sinus 427 kidneys were examined in this respect and the results are given in Table 2

Table 2 Ramification of renal artery in the clinical angiographic material

Side	Proximal		Medial		Distal		Sinus		Total
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	
Right	21	9.9	33	15.5	114	53.5	45	21.1	213
Left	10	4.7	20	9.3	90	42.1	94	43.9	214
	31	7.3	53	12.4	204	47.8	139	32.5	427

Table 3 Number of branches of renal artery before renal hilum in the clinical angiographic material

Side	No ramification		2 arteries		3 arteries		4 or more arteries		*Total*
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	
Right	45	21.1	100	47.0	51	23.9	17	8.0	213
Left	94	43.9	91	42.5	22	10.3	7	3.3	214
	139	*32.6*	*191*	*44.7*	*73*	*17.1*	*24*	*5.6*	*427*

The number of branches into which the artery divided before entering the kidney was also studied and the results are given in Table 3

Corresponding analysis of the topography of the arteries in the 23 kidneys removed *post mortem* showed that 4 or more branches were found before the hilum in 16 kidneys and in only 1 kidney did the renal artery branch in the sinus Proximal division of the artery was noted in 4 kidneys, medial in 6 and distal in 12 while in 1, as mentioned, the artery did not divide until it reached the sinus

ORIGIN, COURSE, AND SEGMENTAL DISTRIBUTION OF THE BRANCHES OF THE RENAL ARTERY IN 156 KIDNEYS

Pyr 1–2 VD — [illegible] aried considerably (Table 4 and Fig [illegible] was supplied by arteries emanating [illegible] arteries In two thirds of these kidneys r ventr pyr 1–2 V was just as wide as r dors pyr 1–2 D (Figs 12 and 23) In the other kidneys the branches of the ventral artery were definitely wider, which implies that r ventr was responsible for

Fig 10 Selective renal angiogram of a left ptotic kidney Renal artery is elongated straightened and has a steeply descending course Field of supply of dorsal artery includes pyr 1 ° V D Renal artery divides into three arteries

a renal s	—	a dors pyr 1 ° V 1 6 D
	—	a ventr pyr 3–4 V
	—	r inf pyr 5 7 V 7 D

the main supply of the segment The branches of the dorsal artery often multiple were frequently small and supplied only those parts of the pyr 1 2 D near the sinus

In 11 5 % the segment was supplied only by vessels from the ventral artery (Fig 13) and in 21 2 % by vessels from the dorsal artery (Figs 10 15 and 1⁻) The ventral artery and the dorsal artery entered the hilum immediately caudal to pyr 1–2 V D so that r ventr or r dors pyr 1 2 V D had a short main trunk which soon divided into ventral and dorsal subsegmental arteries which followed the calyx to the papillae On their way the segmental arteries gave off

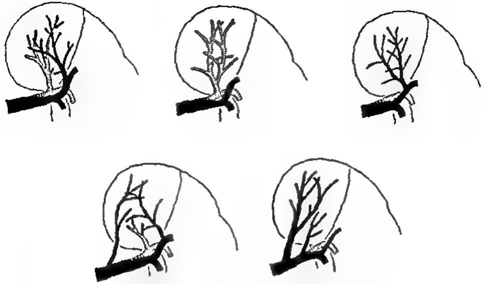


Fig. 11. Diagram of left upper renal pole showing common variations of arterial supply of pyr. 1 2 VD

Table 4. Variations in origin of arteries to pyr. 1 2 VD in the clinical and autopsy material

Kidneys studied	Origin from							
	a. renalis	a. renalis and			a. ventr.	a. dors.	a. ventralis and a. dorsalis	
		a. ventr.	a. dors.	a. ventr. + a. dors.			ventr. largest	equally large
Angiograms in one plane (100)	3	4	10	3	12	21	16	31
Angiograms in two planes (33)	0	0	4	1	5	6	7	10
Post mortem specimens (23)	1	1	0	0	1	6	3	11
Total (156)	4	5	14	4	18	33	26	52
Per cent	2.6	3.2	8.9	2.6	11.5	21.2	16.7	33.3
		14.7					50.0	

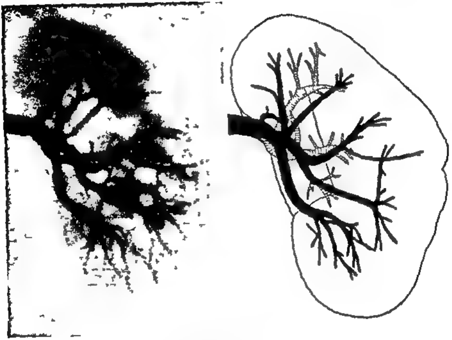


Fig 12 Selective renal angiogram (left kidney) Pyr 1 2 VD is supplied by a dorsal as well as a ventral artery

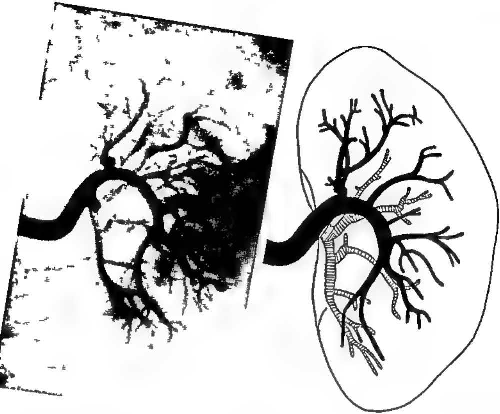
a renalis — a dors pyr 1–5 D
a ventr pyr 1–7 V, 6 7 D

branches to neighbouring parenchyma The segment was often supplied by several small arteries instead of one large one

In 2 6 % of the kidneys one or more branches left the renal artery before the dorsal artery to supply pyr 1–2 VD (Fig 21) In 14 7 % at least one branch left the renal artery before or at the same level as the dorsal artery, but the segment was also supplied by vessels from the ventral and dorsal arteries (Fig 6)

In 145 (93 %) kidneys the supply was limited to this segment In 11 the supply also covered pyr 3 V, and in ■ of them the pyr 3 D as well

Pyr 6–7 VD — One artery to the lower pole was always demonstrable Its area of supply varied, as did the level of origin from the renal or the ventral artery (Fig 14, Table 5)



a

b

Fig 13 Selective renal angiogram (left kidney)

a–b Frontal projection Ventral artery supplies pyr 1 2 V D dorsal artery dorsal part of pars inferior Ventral artery to lower pole arises as last artery and runs parallel to lateral kidney surface

|a renalis|—— a dors pyr 3 7 D
| |—— a ventr pyr 1 7 V 1 2 D

In 60 (38 5 %) kidneys the artery to the lower pole arose from the renal artery either before (29 cases) or at the same level as (31 cases) the dorsal artery (Fig 10)

In 96 (61 5 %) kidneys the artery to the lower pole originated from the ventral artery most frequently where the latter entered the kidney hilum (Figs 8, 19 and 22) In 55 (57 3 %) of these kidneys the artery ran to the lower pole as the first branch of the ventral artery (Figs 8, 12 and 15) and in 27 (28 1 %) kidneys as the last branch (Fig 13) In the remaining 14 (14 6 %) kidneys the origin from the ventral artery varied the lower polar artery usually arose

Fig 13c Oblique projection Observe increased distance between dorsal and ventral artery as compared with frontal projection

immediately distal to the origin of r ventr pyr 1 2 V (D) or at the same location and then as a member of a trifurcation in which the r ventr pyr 3 5 V was the third component (Fig 14 Table 5)

The course of the lower polar artery in the sinus varied with its origin (Fig 14) As mentioned the renal artery or its main branches nearly always ran in the upper part of the hilum cranial to the renal pelvis or at the level of the upper part of the confluence of the kidney pelvis In the majority of kidneys (more than 80 % of the material) where the lower polar artery emanated from the renal artery or early from the ventral artery the vessel ran a latero caudal course to the lateral lower hilar angle The more central the origin of the lower polar artery in the sinus the more vertical was its course In the 27 kidneys in which the artery to the lower pole was the last branch of the ventral artery both often ran a characteristic longitudinal course in most cases parallel

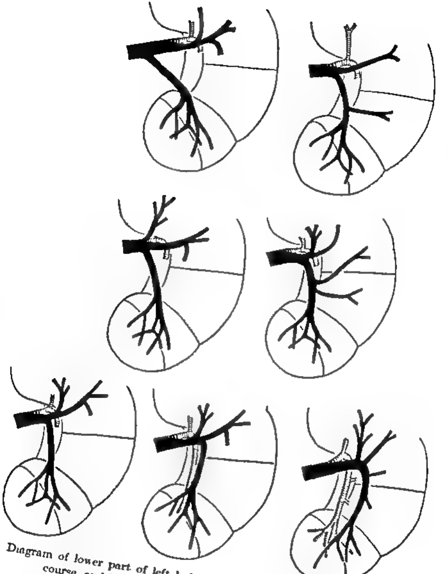


Fig 14 Diagram of lower part of left kidney showing common variations in origin, course and field of supply of artery to lower pole

o the dorsal artery The ventral artery in these cases entered the upper hilum, here it ran an almost horizontal course, after which it turned caudally in e lateral part of the sinus and then ran parallel to the lateral surface of the

Table 5 Variations in field of supply and origin of lower polar artery (clinical and autopsy material)

Pyramids supplied	Origin from renal artery				Origin from ventral artery					Total	
	Before d renal artery	*Tri furc*	*Quadri furc*	*Num ber*	*1 st branch*	*2 nd branch*	*Tri furc*	*Last branch*	*Num ber*	*Num ber*	*Per cent*
4 7 V				0		1		1	2	2	1 3
5 7 V		3	1	4	3	2			5	[illegible]	5 8
6 7 V	3	2		5	1	1	1	15	18	23	14 7
6 7 V 6–7 D	12	7		19	19		1	6	26	45	28 8
6 7 V 7 D	2	2	3	7	5	1	2	3	11	18	11 5
5 7 V 5–7 D	1			1					0	1	0 7
5–7 V 6 7 D	9	8	1	18	19	4			23	41	26 3
5–7 V 7 D	2	3		5	5		1		6	11	7 0
4 7 V 6–7 D		1		1	2			2	4	5	3 2
4 7 V 7 D				0	1				1	1	0 7
Number	29	26	5	60	55	9	5	27	96	156	
Per cent	18 6	16 7	3 2	38 5	35 2	5 8	3 2	17 3	61 5		

kidney During its course it gave off branches first to pyr 1–2 V (D) then to 3–5 V and finally to 6–7 V (D) (Fig 13)

In none of the kidneys (56) examined in more than one *projection* did the artery to the lower pole run dorsally to the renal pelvis Before the artery divided and entered the parenchyma it ran adjacent to the lower calyx as far as the level of the papillae In the cases in which it supplied dorsal pyramids the artery gave off a branch to pyr (6)–7 D as a rule at the level of the lower calyx but occasionally proximal thereto

The lower polar artery is above all a ventral artery and therefore regularly supplied pyr 6–7 V Its field of supply often included pyr 5 V (Figs 8 and 10) and rarely pyr 4 V (Fig 19 Table 5)

In 122 (78 2 %) of 156 kidneys the lower polar artery supplied not only the two ventral pyramids but also pyr 7 D (Figs 8 10 and 21) and in 92 (59 0 %) it supplied the entire pars inferior (Figs 6 12 15 and 19) Only in one kidney did the supply include not only pars inferior but also pyr 5 V and D When the lower polar artery did not supply the dorsal pyramids in the pars inferior this part was supplied by the dorsal artery (Figs 13 and 17)

In the 27 kidneys in which the artery to the lower pole was the last branch from the ventral artery its field of supply was more ventral than otherwise In 16 (59 2 %) of these kidneys it therefore supplied ventral pyramids only as against only *18 (14 0 %) of 129* in the rest of the material (Table 5 Fig 13)

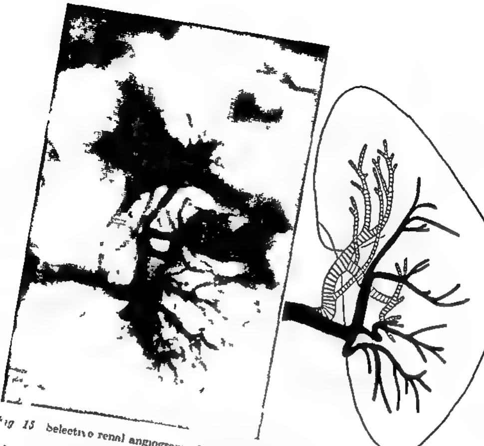


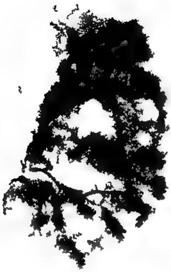
Fig 15 Selective renal angiogram of a normal left kidney extirpated later because of severe haematuria

a–b Frontal clinical angiogram Dorsal artery runs in an ordinary way to upper part of hilum and supplies dorsal part of pars intermedia and entire pyr 1 2 V D while the ventral artery has an unusual course to lower part of hilum

a renalis	—	a dors pyr 1 2 V 1–5 D
		a ventr pyr 3–7 V, 6–7 D

c–f Angiogram of operative specimen in true frontal (c–d) and lateral view (e–f) confirms findings in clinical angiogram Ventral arteries are filled with water soluble contrast medium the dorsal artery with colloidal $BaSO_4$

Pyr 3–5 V — The subsegmental supply to the individual pyramids was more predominant in the ventral part of the pars intermedia than in any other part of the kidney The subsegmental supply to pyr 3 V was also often prominent but only in relatively few cases (8 kidneys=5 1 %) was each of the 3 pyramids supplied by its own subsegmental artery from the ventral



c

d

e

f

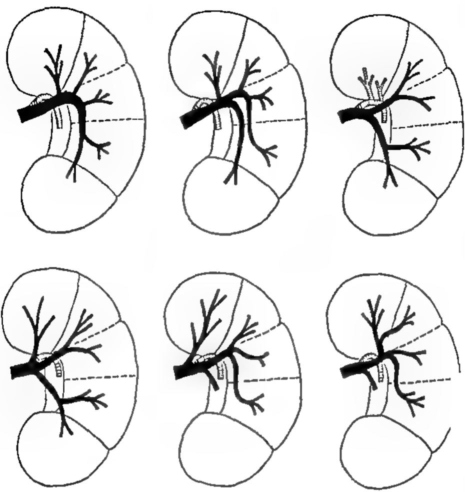


Fig 16 Diagram of left kidney showing common variations in origin, course and fie of supply of segmental arteries to pyr 3 5 V

artery More commonly (86 kidneys=55 1 %) one pyramid (3 V or 5 V) wa supplied separately, while the other 2 were supplied by a common segment artery (4 5 V or 3–4 V) (Figs 9 and 10) In 51 (32 7 %) kidneys pyr 3-5 V were supplied by a common branch of the ventral artery (Figs 16, 17, Table 6) In the remaining cases (11 kidneys=7 1 %) the supply was somewhat differen in that a branch of the ventral artery to pyr 1–2 V also supplied 3 V. Pyr 4–5 V in these kidneys were supplied either by separate branches (Fig 6) or by a common branch of the ventral artery (Table 6)

Table 6 Variations in the supply of pyr 3–5 V

Kidneys studied	3 V, 4–5 V	3–4 V, 5 V	3–5 V	3 V, 4 V, 5 V	1–3 V, 4 V, 5 V	1 3 V, 4 5 V	Total
Angiograms in one plane	6	49	37	3	2	3	100
Angiograms in two planes	3	12	13	2	1	[illegible]	33
Post mortem specimens	4	12	1	3	1	2	23
Number	13	73	51	8	4	7	156
Per cent	*8.3*	*46.8*	*32.7*	*5.1*	*2.6*	*4.5*	

The range of variation of the vascular pattern of the vessels to pyr 1–2 VD and 6–7 VD was limited by the outline of the kidney poles. The variations in the pattern of the vessels supplying pyr 3–5 V were dependent on variations in the arteries supplying the two polar segments while pyr 3 V might be supplied by the artery to pyr 1 2 V (11 kidneys) and 5 V (70 kidneys) and 4 V (8 kidneys), by the artery to pyr 6–7 V (D). In addition, the origin of the segmental arteries to the poles varied with an associated wide variation in the course of the vessels to pyr 3 5 V (Fig 16).

Despite variations in other arteries the artery to pyr 3–4 V usually showed a characteristic course. It formed the direct continuation of the ventral artery, independent of the fact whether r ventr pyr 1–2 V (D) was given off before the segmental artery or not (Fig 17). Exceptions to the rule could, however, be seen (Fig 15). In those kidneys (11) in which pyr 3 V was supplied by arteries to pyr 1–2 V, the artery to pyr 4 V was the continuation of the ventral artery sometimes in combination with the artery to 5 V. In the 27 kidneys, in which the lower polar artery was the last branch the arteries to the pyr 3–5 V in that segment were given off either separately to each pyramid or in various combinations of the type illustrated in Table 6. In these kidneys the segmental artery was given off late because of the lateral position of the ventral artery in the sinus (Fig 13).

In one kidney an artery stemmed separately from the renal artery to pyr 3 V before the origin of the dorsal artery. In 8 kidneys a branch of the renal artery was given off to pyr 3 4 V and in 8 kidneys a branch to pyr 3–5 V as a member of a tri or quadrifurcation, where other arteries were represented by the dorsal artery and arteries to pyr 1–2 VD and 6–7 VD (Fig 10).

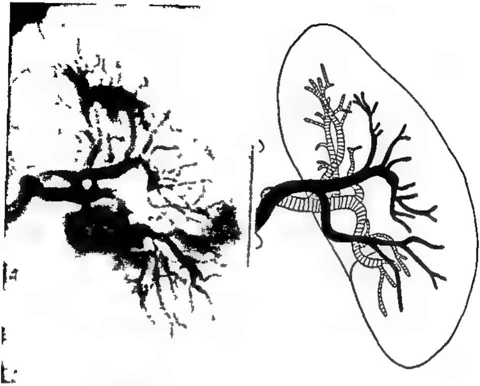


Fig 17 Selective renal angiogram (left kidney) Observe dorsal artery of about same caliber as ventral artery but supplies a larger number of pyramids Pyr 3–5 V is supplied by a main trunk which is a direct continuation of renal artery R ventr pyr 5 V runs *parallel to dorsal artery and lateral surface of kidney Pyr 6–7 D is supplied by dorsal* artery

[a renalis]—[ ]—a dors pyr 1 2 V, 1–7 D
a ventr pyr 3 7 V

The commonest variant of the ventral artery was the one, in which it divided after the origin of the lower polar artery into two branches, one to pyr 1–2 V (D) and one to pyr 3–4(–5) V (76/156=48 7 %)

As to r ventr pyr 5 V the vessel emanated separately from the renal artery in 4 kidneys (2 6 %) and from the lower polar artery in 70 kidneys (44 9 %) The course of the branch to pyr 5 V in the former cases was caudolateral, while the more caudal the origin from the lower polar artery, the more horizontal was its course (Fig 18) Occasionally the segmental artery ran craniolaterally when it was given off from a distal part of the lower polar artery

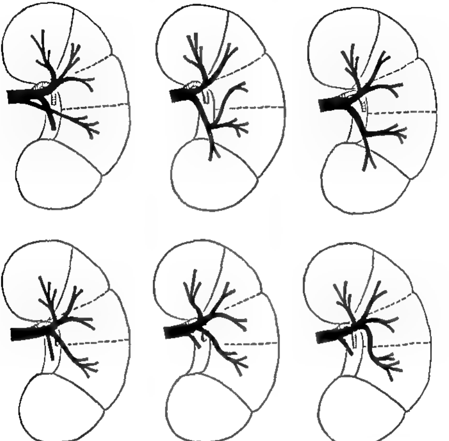


Fig. 18. Diagram of left kidney showing common variations in origin and course of r. ventr. pyr. 5 V.

This was so in the kidneys in which r. ventr. pyr. 4 V also emanated from the lower polar artery (Fig. 19). In one kidney the subsegmental artery was given off in the angle between the artery to pyr. 3–4 V and the lower polar artery. In the remainder of the kidneys the r. ventr. pyr. 5 V branched from the artery to 3–4 V. The r. ventr. pyr. 5 V was, as a rule, given off last, but sometimes it stemmed from the ventral artery before the segmental artery to pyr. 1–2 V (D) (Fig. 18).

The artery to pyr. 3–4 V represented the last part of the ventral artery and

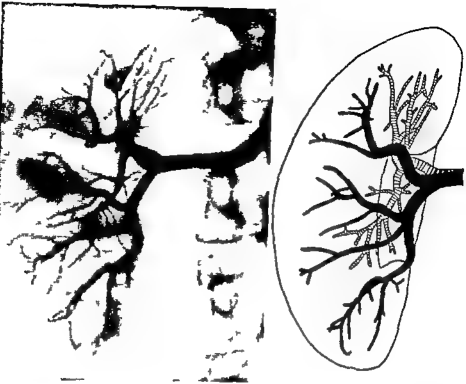


Fig. 19. Selective renal angiogram (right kidney). R. ventr. pyr. 4 and 5 V. arise from r. ventr. pyr. 6–7 V, D and have an ascending and horizontal course, respectively.

a. renalis — a. dors. pyr. 1 2 V 1 5 D
a. ventr. pyr. 3 7 V ■ D

in the sinus it usually ran horizontally or somewhat cranially before its bifurcation in the upper part of the sinus. As a rule it ran cranial to the renal pelvis and crossed the basal part of the upper calyx. After the bifurcation the r. ventr. pyr. 3 V ascended somewhat, while r. ventr. pyr. 4 V ran slightly caudally or horizontally. The former vessel ran adjacent to the upper calyx on the lateral side up to its pyramid, while ■ ventr. pyr. 4 V followed one of the middle calyces.

R. ventr. pyr. 5 V, when it arose from the artery to pyr. 3–4 V, usually ran caudally along the lateral border of the sinus of the kidney and finally followed ■ calyx to its pyramid (Fig. 17).

Pyr. 3–5 D. — As a rule the dorsal artery originated from the renal artery before the hilum (Fig. 20). In 80 (51.3 %) of 156 kidneys the renal artery

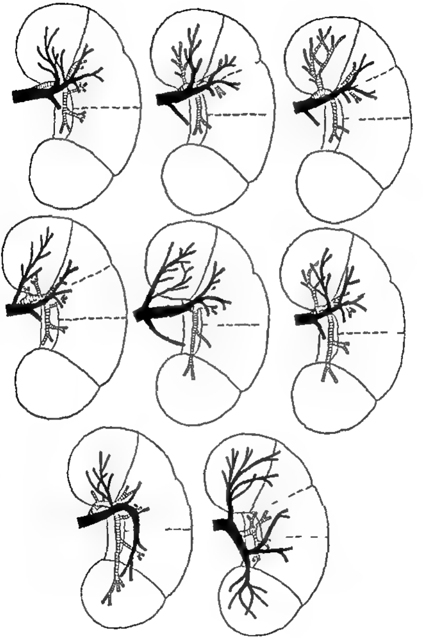


Fig. [illegible]. Diagram of left kidney showing common variations in origin, course and field of supply of dorsal artery.

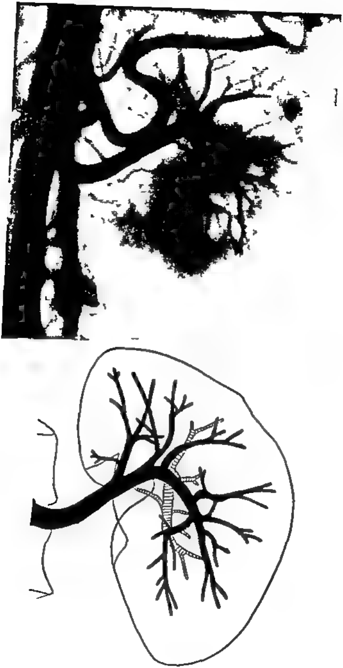


Fig 21

divided into a ventral and a dorsal main branch without giving off any previous branches (Figs 8 13 16 and 17) In 39 (25 0 %) of 156 kidneys the dorsal artery was given off at the same time as 2 or 3 branches to the 3 other segments in the kidney (Fig 10) In 37 kidneys minor branches were given off from the renal artery before the dorsal artery usually to pyr 1 2 V D segment (Fig 6) or pyr 6–7 V D rarely to pyr 3 5 V In 2 kidneys the dorsal artery was given off distally in the sinus together with r ventr pyr 3–4 V (Fig 21) In 3 kidneys the dorsal artery arose from r inf pyr 6 7 V D Finally in one kidney two dorsal arteries were observed one originated from the renal artery and supplied pyr 1 2 D and 6 D the other supplied 3 5 D and arose from the lower polar artery Only in a few kidneys did the dorsal artery divide before the hilum The dorsal artery was in rare cases as wide as the ventral artery (Fig 17)

The dorsal artery usually entered the upper part of the hilum as a single vessel and there in most cases ran an almost horizontal course Most frequently it gave off branches to pyr 1 2 D which varied from small often multiple vessels supplying adjacent regions of pyr 1 2 D to one wide artery supplying the entire pyr 1 2 V D (Figs 10 16 and 17) The artery then turned caudally to run an almost vertical course In the clinical renal angiograms this curve was not always distinct because of the position of the kidney *in vivo* (Fig 8) The cranio lateral convexity usually gave off the branches r dors pyr 3 D sometimes 4 D which followed the calyx to the tip of the pyramid During its further course the dorsal artery gave off branches to pyr 4 and 5 D These branches came from the lateral aspect or the terminal part of the dorsal artery

As mentioned (page 27) in 5 kidneys the pyr 3 D was supplied by the artery belonging to pyr 1 2 V D segment In 3 of these the vessel arose from the dorsal artery in one from the ventral artery and in one from the renal artery Pyr 5 D was supplied in one kidney by an artery belonging to pyr 6–7 V D segment Pyr 4 D was regularly supplied by the dorsal artery (Table 7 Fig 20)

It was thus possible to show that pyr 3 5 D was nearly always (98 %) supplied by the dorsal artery

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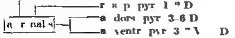
Fig 1 Aortic renal angiogram (left kidney) Pyr 1 2 V D is supplied by arteries from renal artery dorsal artery departs late in sinus



angiographic study showed that more than half of the right renal arteries (52 %) have a descending course and seldom (9 %) ascending However the course of the left renal artery in 40 % was found to be ascending and only 16 % descending with as many as one third of the latter being situated lower than normal

If the findings of EDSMAN (1957) are taken into account then it is possible to decide in a plain film the course of the artery to the kidney as being from the level of the intervertebral disc between the first and second lumbar vertebrae to the upper part of the hilum of the kidney This is of practical importance in performing selective renal angiography On insertion of the catheter into the renal artery the bent tip should more or less correspond to the course of it to facilitate positioning of the catheter and to prevent the tip of the catheter from being directed against the arterial wall When the renal artery has a markedly descending course it might be difficult to feed the tip of the catheter into the artery unless it is bent in a curve to almost 180° By determining the position of the kidney in relation to the intervertebral disc between L I and L II in plain roentgenograms before angiography it is thus possible to shape the catheter according to the course of the vessel

RAMIFICATION OF THE RENAL ARTERY

In earlier morphologic studies the renal artery has been found to divide before the hilum as a rule into 4 or 5 branches Similar results were obtained in 65 % of kidneys removed *post mortem* in the present series The frequency found by clinical angiography was definitely lower (5 %, Table 3) On the other hand the origin of the first branches of the renal artery varied less in this respect Table 8 compares these frequencies with those found in the present investigation

The present clinical material differs from the autopsy studies described by other authors because the renal artery runs not only laterally but also dorsally In clinical angiograms the renal artery appears shorter and particularly its terminal part which is projected over the medial part of the kidney as is clearly shown by the *post mortem* specimens examined in different projections (Fig 8) Thus the findings made at autopsy are not strictly comparable with those made by clinical angiograms

PALUMBO (1952) using angiograms of kidneys removed *post mortem* showed good agreement with our clinical results These results differed considerably from those reported by earlier authors and from those made in the present *post mortem* investigation This difference may be explained by the fact that PALUMBO examined preparations at an angle corresponding to the frontal projection *in vivo*

Table 8 Origin of first branches from renal artery in previous and present autopsy studies compared with the present clinical material

Author	Number of cases	*Proximal origin*	*Medial origin*	*Distal origin and origin in sinus*
Gérard (1911)	207	[illegible] %	14 %	68 %
Hou Jensen (1930)	50	12 %	20 %	68 %
Palumbo (1952)	34	6 %	12 %	82 %
Present				
1) *Post mortem*	23	17 %	26 %	57 %
2) In vivo	427	7 %	12 %	81 %

It is clear from the present clinical angiographic studies that in about 7 % a branch arises proximally from the renal artery. This is important in selective renal angiography because it may result in the tip of the catheter entering the narrow early branch. This may cause a spasm with the risk of complications because the renal artery is an end artery (Fig. 22). *If a spasm does not occur* all the contrast medium may be deposited in that segment supplied by the proximal branch with demonstration of only part of the kidney. Consequently *the bent tip of the catheter should not extend more than about 1 cm into the renal artery.* The tip of the catheter should be situated immediately adjacent to the *left border of the vertebral body when* catheterizing the left renal artery and about 1 cm medial to the right border of the vertebral body on catheterization of the right renal artery.

In the present clinical series the right *renal artery was found to divide* proximal to the hilum *twice as often as the left.* This may be due to the fact that the right renal artery is somewhat *longer than the left* (CALLANDER 1939 and others).

ORIGIN, COURSE AND SEGMENTAL *DISTRIBUTION OF THE BRANCHES* *OF THE RENAL ARTERY*

Pyr 1–2 I D. — This segment, which corresponds to the medial and superior part of the upper renal pole, *had a separate arterial supply in* 93 % of the kidneys, while in the remaining 11 (7 %) kidneys the arterial supply seemed *to extend to the entire pars superior.* In 6 of these kidneys it could not be decided with certainty whether the artery supplied pyr. 3 D or 4 D. LOFGREN (1949) showed that pyr. 3 D is the one that is usually least developed

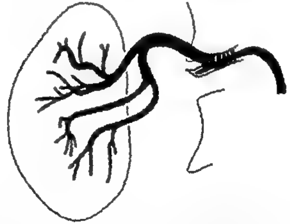


Fig Select o renal ang ogram (r ght k lney) Tip of catl eter s placed arter a i ng spasm n tl s vessel Only ventral artery tl erefore f ll l. Obse branches of entral artery l) not cross o e anotl er

an l in several cases this pyramid is only rudimentary Pyr 4 D is thus s more cranially an l the vessel to the pyramid is then read ly mistake dors pyr 3 D It is probable that in 7 % of the cases the pars s iper suppl ed by in lependent arteries from the dorsal an l/or ventral artery

I yr 1 9 \ D corresponds to what was usually described by earlier

as the upper pole (BRODEL 1901, GREGOIRE 1906, ALBARRAN & PAPIN 1908, BELLOCQ 1914, *HOU-JENSEN 1930 SMITHUIS 1956* and others) Opinions have differed widely on its vascular supply This disagreement can be explained by the fact that there is a wide variation in the blood supply, and also that opinions differ on what should be regarded as the exact limits of the upper pole GRAVES (1954) charted the supply to the upper pole in segments, an apical an upper *and a posterior The 2 last mentioned extended down into the* pars intermedia on the ventral and dorsal sides respectively The apical segment did not correspond to pyr 1–2 VD but represented either pyr 1–2 V or 1–2 D This, therefore explains the difference between the pattern of the supply found in the present investigation and that described by GRAVES The reason why *preference was given by the present author to a larger segment was that in* 35 % of the kidneys pyr 1–2 VD was supplied by only one artery GRAVES found that the dorsal artery supplied the apical segment in only 10 % of the kidneys, while the ventral artery did so in 43 3 % of kidneys This can be explained by the fact that the upper portion of the ventro medial part of the kidney usually consists of pyr 1–2 V and that ventral branches supply parts of the dorsal pyramids GRAVES found that arteries to the apical segment stemmed from the aorta or renal artery in 46 6 % of kidneys as against 17 3 % to pyr 1–2 VD in the present investigation This can be explained by the fact that the present material included only kidneys with a single renal artery According to HELLSTROM (1928) and BERGENDAL (1936) arteries are given off by the aorta to the upper pole in about 7 % The remaining approximately 22 % of kidneys may be explained by differences in the classification of the *origin of the segmental arteries The segmental artery to pyr 1–2 VD arises* very close to that of the dorsal artery from the renal artery, so that in the present material the origin of r ventr pyr 1–2 V was considered to be from the ventral artery GRAVES on the other hand, considered the artery to branch simultaneously with the dorsal and ventral arteries from the renal artery

HELLSTROM (1928) found that in 22 % there was an extrahilar artery from the renal artery to the upper renal pole In the present material 19 kidneys (12 2 %) were found to have extrahilar arteries running to the pars superior In 11 kidneys *these vessels ran from the renal artery, and in the remainder from the ventral or dorsal arteries* Since these vessels often enter the renal parenchyma quite close to the hilum angiography will not always decide whether the artery runs within or outside the sinus There was thus reason to suppose that many more arteries ran outside the hilum to the upper pole *than we found*

Pyr 6–7 VD — It is known that the artery to the lower pole of the kidney usually arises from the ventral artery (BELLOCQ 1914, HOU-JENSEN 1930 and

others) GRAVES (1954) believed that this artery was the most characteristic and consistent in the vascular tree HOU JENSEN (1930) found that in about 77 % (23/30 kidneys) both the ventral and dorsal part of the lower pole were supplied by this artery while in the remaining cases the dorsal artery itself was responsible for the nutrition of the dorsal portion GRAVES (1954) did not mention this variant In 78 % of the kidneys in the present material pyr 6 7 V and 7 D were supplied by the lower polar artery while pyr 6 7 V D were supplied in 59 % In 22 % of kidneys the ventral pyramids alone were supplied which was particularly common in those kidneys in which the lower polar artery was given off as the last branch of the ventral artery Pyr 6–7 V D corresponds entirely to the segment GRAVES (1954) called lower segment Nutrition of the whole segment was seen in almost 79 % of kidneys distinguished by a sharp demarcation against the pars intermedia (Table 5) In a further 30 % of the cases the vessel to the lower pole also supplied pyr (4)5 V

GRAVES (1954) found that the lower polar artery stemmed from the ventral artery as the first branch in 63 % of the cases In the present material it was found that the lower polar artery (r inf pyr 6–7 V (D)) originated from the renal artery at the same level (20 %) as the dorsal artery or before (18 5 %) while in the rest of the kidneys it stemmed from the ventral artery Thus the r ventr pyr 6–7 V D represented the first branch of the ventral artery in 57 3 % in the rest of the kidneys In contradistinction hereto in 51 3 % the dorsal artery was the first branch given off by the renal artery and in a further 25 % it left the renal artery together with 2 or 3 other arteries

Pyr 3 5 V — This segment corresponds to the ventral mid portion of the kidney as described by ALBARRAN & PAPIN (1903) They found that the two intermediate ventral arteries ran to this portion of the kidney GRAVES (1954) upper and middle segments correspond approximately to pyr 3–4 V and pyr 5 V when pyr 1–2 V coincides with his apical segment Each pyramid in this segment was supplied by a separate artery (subsegmental artery) usually stemming from a branch (segmental artery) given off by the ventral artery Usually the r ventr pyr 3–4 V arose from the ventral artery When r ventr pyr 5 V was a separate branch it arose either from the same trunk as that from which the other two pyramids were supplied or from the lower polar artery The findings agree essentially with those described by GRAVES (1954) In a few cases r ventr pyr 3 V and 5 V arose separately from the renal artery A further variant noted pyr 3 V was sometimes supplied by arteries belonging to pyr 1 2 V D It is remarkable that pyr 3 V which belongs to the pars superior was not supplied by the same vessels as pyr 1–2 V D As mentioned the border of the segments are not quite distinct and the upper

part of pyr 3 V is therefore supplied by the vessels to pyr 1–2 VD but the main supply emanates from the branch to pyr 4–5 V

Pyr 3 5 D — The area supplied by the dorsal artery varied considerably but it almost always included pyr 3–5 D The dorsal artery supplied not only this segment but often extended in both a cranial and caudal direction and in more than 20 % of the cases it also supplied pyr 1–2 VD and occasionally pyr 1 3 VD None of the other ventral pyramids received any supply from the dorsal artery

BRODEL (1901) and others believed the ventral artery to supply ventral parts of the dorsal pyramids The ventral artery can supply the major portion of the dorsal pyramids in the pyr 1–2 VD segment as shown (page 25) and small arteries were seen extending from the dorsal artery to pyr 1–2 D which supplied those parts of the dorsal pyramids near the sinus The ventral artery to the lower pole was often the only supply to the dorsal pyramids there A ventral and a dorsal area of supply were always recognized in the pars intermedia where the segmental arrangement is best preserved The calibers of the ventral artery and its branches were larger than those of the dorsal artery when compared with the number of pyramids supplied This supports the view of BRODEL (1901) HOU JENSEN (1930) and LOFGREN (1949) that the ventral artery also supplies the ventral parts of the dorsal pyramids The branches of the ventral artery were never found to cross one another in the pars intermedia (Fig 22) as they did in pars superior and inferior where they supplied entire dorsal pyramids This interlacing of the ventral artery and dorsal artery described by FUCHS (1931) and LOFGREN (1949) was thus localized to the poles

It is characteristic that segmental or subsegmental arteries supplying dorsal pyramids cross arteries supplying ventral pyramids Should selective renal angiography miss such a crossing in any region of the kidney a supplementary artery must be assumed If the kidney is examined in more than one projection it will be easier to detect whether any vessels are missing, but once sufficient experience has been gained a single projection will be enough

The natural division of the kidney as described by HYRTL (1872) could thus be found only within the pars intermedia posterior to the sulcus longitudinalis There is little risk of injury to the larger vessels in association with transrenal pyelolithotomy when the field is approached dorsal to sulcus longitudinalis This sulcus is always seen in the middle part (pars intermedia) of the kidney

The value of preoperative renal angiography has been confirmed by many surgeons especially if partial resection is contemplated (LJUNGGREN 1952, SEMB 1953 1955 SCHULZE BERGMANN 1957 and others) particularly since it

usually is the lower pole that is resected (STEWART 1952 1953) Observations made in the present material showed that the lower pole is most accessible to resection because in 60 per cent of all kidneys both the ventral and the dorsal pyramids in the pars inferior are supplied by a single artery which courses ventrally over the renal pelvis (Figs 15 and 23) In half of these cases this artery gives off branches early in the sinus and these branches run to the lower part of the pars intermedia ventralis On resection of the pars inferior in these cases the lower polar artery may be ligated distally to the departure of the r ventr pyr 5 V

In the remaining 40 per cent of kidneys the dorsal artery supplies the entire dorsal part or the proximal part of the dorsal half of pars inferior

Course of arteries in the sinus — To divide the vasculature into different types as KUPRIJANOFF (1924) did proved unsuitable On the other hand the individual segmental arteries showed a fairly characteristic course so that the supply to the various segments could be readily recognized

If the renal artery passed undivided into a kidney the vessel nearly always entered the cranial part of the sinus independent of whether the vessel had previously ascended descended or run horizontally If the renal artery divided before it reached the hilum the ventral artery and dorsal artery entered the upper sinus and gave off branches on their way to the various segments of the kidney The courses of these vessels were fairly constant

Ventral artery — The r ventr pyr 1–2 V (D) when present usually stemmed early from the ventral artery and ran along the upper calyx craniolaterally or cranially

R ventr pyr 3 4(5) V was the direct continuation of the ventral artery and as a rule ran almost horizontally If r ventr pyr 5 V was present it ran caudally and often parallel to the lateral border of the kidney in the lateral aspect of the sinus where it could follow a calyx to its pyramid The subsegmental arteries to pyr 3 V and 4 V ran radially to their respective pyramids

R ventr pyr 6–7 V (D) usually arose early from the ventral artery and as a rule ran caudolaterally and crossed the confluence of the kidney pelvis on the ventral side Sometimes the lower polar artery may arise early from *the renal artery and cross the uretero pelvic junction (BOIJSEN to be published)* This is of the greatest importance from a surgical point of view because it favours obstruction of the uretero pelvic junction In none of the cases studied in the present investigation was any vessel supplying the ventral part of the lower pole seen to run dorsally to the renal pelvis nor did a dorsal artery ever supply the ventral pyramids The lower polar artery sometimes gave off dorsal branches early to pyr (6) 7 D Before reaching the confluence of the kidney pelvis r inf or ventr pyr 6–7 V D sometimes gave off one branch

coursing behind it to the dorsal part of the kidney and another passing in front of it to pyr 6–7 V Sometimes a branch left the dorsal artery early and ran to pyr 6–7 D parallel to r ventr pyr 6–7 V

The more central the origin of the lower polar artery in the kidney the more vertically did it run The renal arteries also showed a characteristic course corresponding to that given by KUPRIJANOFF (1924) for Typus magistralis I or longitudinalis (NARATH 1951) when r ventr pyr 6–7 V (D) stemmed as the last vessel from the ventral artery The dorsal and ventral arteries then ran parallel to one another either within (Fig 13) or outside of the sinus medial to the kidney giving off segmental arteries on its way but such a course was unusual

If r ventr pyr 5 V stemmed from a proximal part of the lower polar artery it ran caudo laterally to the pyramid if it arose from a distal part it ran horizontally

The radiating branches of the ventral artery described by ALBARRAN & PAPIN (1908) and HOU JENSEN (1930) can be confirmed because the different ventral segmental arteries diverge from a point usually represented by the origin of the lower polar artery from the ventral artery The point was situated within or outside the sinus at the level of the upper part of the hilum This fan like appearance was absent in those cases in which r ventr pyr 6–7 V (D) was given off as the last branch

The dorsal artery nearly always has a characteristic course In 50 % of all cases it was the first vessel to branch from the renal artery and its appearance as seen in the angiograms agreed with that described by earlier investigators (ALBARRAN & PAPIN 1908 HOU JENSEN 1930 GRAVES 1954 and others) provided of course that allowance be made for the position of a kidney *in vivo* HELLSTROM (1928) stressed the importance of the surgeon being acquainted with the course of this vessel which was often concealed behind the posterior hilar lip and could readily be injured in association with pyelotomy

Apart from the fact that the segmental arteries usually follow the calyces it is not possible to demonstrate any relation between the degree of ramification of the renal pelvis and the vascular pattern In the sinus the ventral and dorsal branches of the renal artery lie close to one another so that the vessels under certain circumstances can cause impressions on the renal pelvis (Fig 23) This will be the subject of a future paper

After having examined angiograms of 23 kidneys removed *post mortem* it was found that it was not possible to chart the vasculature more exactly than by angiography *in vivo* The findings at autopsy were however included in the material for evaluation of the vascular supply to the various segments Examination of the kidneys at autopsy from different angles demonstrated

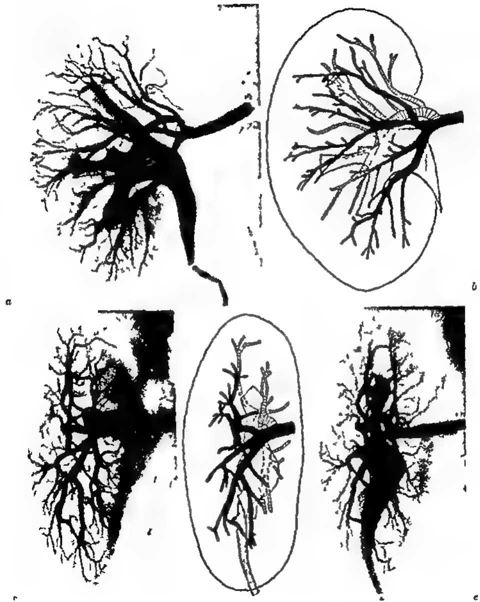


Fig. 23. Autopsy specimen (right kidney). True frontal (a–b) and lateral (c–e) projection. Observe closeness of ventral and dorsal arteries in sinus.

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Broadly speaking a ventral and a dorsal region of supply were recognized which were located in the pars intermedia From the pars intermedia ventral and dorsal arteries extended their supply in both cranial and caudal directions The dorsal artery supplied predominantly in a cranial direction so that the ventral pyramids (pyr 1 2 V) could also be encompassed the ventral artery in a caudal direction so that the dorsal pyramids in the pars inferior (pyr 6 7 D) could also be supplied The ventral artery also supplied dorsal pyramids in the pars superior and ventral parts of the dorsal pyramids in the pars intermedia but was never the only source of supply to the latter

Origin and course of the segmental arteries — The pattern of the various segmental arteries in the sinus was fairly constant The variations observed were due to differences in the level at which they branched from the renal dorsal and ventral arteries

In the pars intermedia branches from the dorsal artery did not cross each other but crossed branches from the ventral artery In the poles however the branches from a primary artery could cross each other The branches of the dorsal artery were localised more medial than those of the ventral artery because of the position of the kidney *in vivo* The dorsal artery was usually smaller than the ventral and was the first to branch from the renal artery in about 50 % of kidneys

It is stressed that detailed knowledge of the vascular anatomy is important in surgery and in diagnostic roentgenology The roentgenologist should be familiar with the course of the artery in low lying kidneys as well as be aware of the possibility of segmental branches arising early from the renal artery To be able to exclude the possibility of supplementary arteries in a given case it is necessary to be familiar with the segmental supply of the kidney It was shown that in about 60 % of all cases the pars inferior *i e* that part of the kidney usually resected is supplied by a single artery

the medial position of the dorsal artery *in vivo* These examinations also showed that the peripheral branches of the ventral artery never cross each other as long as the ventral artery supplied only the ventral pyramids This is applicable to peripheral branches of the dorsal artery when they supplied only the dorsal pyramids

The purpose of this investigation was to chart the topography of the renal arteries as they appear in clinical angiograms and thus the autopsy examinations were limited

SUMMARY

The normal roentgen anatomy of the kidney having one renal artery was studied in clinical angiograms and in kidneys removed at autopsy The course of the renal artery from its origin to the renal hilum was studied in 314 kidneys *in vivo* and the ramification of the artery in 427

In the clinical angiograms the origin course and segmental supply of the branches of the renal artery were studied in 133 kidneys 33 of which had been examined in more than one projection (selective angiograms) A total of 23 kidneys removed at autopsy were examined in 3 projections

Course of the renal artery from aorta to renal hilum — The renal artery usually ran a horizontal or descending course on the right side and a horizontal or ascending course on the left The renal artery entered the upper part of the hilum cranial to the renal pelvis In ptosis of the kidney the artery always ran a descending course with the exception of a few cases when the artery on the left side may run horizontally even in the presence of slight ptosis

Ramification of the renal artery — Because of the latero dorsal course of the renal artery and the position of the kidney *in vivo* the branches of the artery medial to the hilum will not be seen as often as in autopsy cases In about 7 % of all kidneys a branch arose early from the renal artery which was important in selective renal angiography

Origin course and segmental distribution of the branches of the renal artery — It was found that the characteristic vascular pattern made it possible to distinguish between ventral and dorsal arteries in a film taken in one plane In nephrograms the pyramidal arrangement could be distinguished

Segmental supply of the renal artery — On the basis of the topographic arrangement of the pyramids in the kidney it was found that the kidney has a segmental supply not coinciding with the borders of the lobes Four segments were recognized namely (I) the two most cranial pairs of pyramids (II) the two most caudal pairs of pyramids (III) the three middle ventral pyramids and (IV) the three middle dorsal pyramids

EARLIER INVESTIGATIONS

FREQUENCY OF MULTIPLE ARTERIES

Autopsy studies. — There is divergence of opinion in the literature as to the frequency of multiple arteries. This lack of agreement is partially due to differences in nomenclature. The frequency given in the literature thus varies between 14 % (SCHMERBER 1895) and 47 % (WEINSTEIN, COUNTISS & DERBES 1940). Most authors, however, give a frequency of 20 % to 30 %. On the basis of a personal series together with data given by 14 other investigators HOU JENSEN (1930) found that of a total of 2 569 kidneys 22.4 % had multiple arteries. Later investigations, however, have revealed a somewhat higher frequency. Thus HELLSTRÖM (1928) gave 26.5 %, ANSON, RICHARDSON & MINEAR (1936) 32.5 %, BERGENDAL (1936) 30.6 %, while MELKONIAN (1954) found multiple arteries in only 16.5 % and BUSCH (1954) in 20.5 %. If these recent investigations be added to those collected by HOU JENSEN it will bring the total up to 4 118 kidneys with multiple arteries in 26.0 %.

Clinical angiographic studies. — EDSMAN (1957) studied the frequency of multiple arteries angiographically. Of 1 240 kidneys he found multiple arteries in 21 %. In patients with hydronephrosis and obstruction of the ureteropelvic junction EDSMAN found multiple arteries in 38 %. In a clinical angiographic series there is always an over-representation of cases of hydronephrosis. If these be excluded, the frequency found by EDSMAN was 20 %.

FIELDS OF SUPPLY, TOPOGRAPHY AND RELATIVE FREQUENCY OF SUPPLEMENTARY ARTERIES

Autopsy studies. — Two types of supplementary arteries were recognized, namely hilar arteries and polar arteries, the latter referring to extrahilar arteries running directly to the parenchyma. The anatomic studies have not shown which regions are supplied by the hilar arteries. The extrahilar arteries run to either pole.

THOMPSON (1891) found in 99 kidneys with multiple arteries an extrahilar

PART II

MULTIPLE RENAL ARTERIES

INTRODUCTION

Multiple arteries are said to be present when the kidney is supplied by more than one artery from the aorta or iliac artery In the literature such arteries as well as extrahilar branches of a single renal artery are often referred to as aberrant accessory abnormal anomalous or supernumerary It is therefore difficult to decide whether an author means a single renal artery with extrahilar branches or arteries arising from the aorta or iliac artery In order to avoid such confusion and because these arteries are end arteries and in addition usually supply as much as 20—50 % of the renal parenchyma these terms are not used at the Roentgen diagnostic Department University Hospital Lund There any artery other than the main renal artery and leaving the aorta or iliac artery is called a *supplementary* artery The term *multiple* arteries is used when reference is made to the entire supply to the kidney (Olle Olsson Encyclopedia of Medical Radiology in print)

As shown (Part I) the branches of the renal artery supply separate segments of the renal parenchyma though the segment or segments supplied by a given branch may vary widely from one kidney to another This variation may be due in part to the arrangement of the pyramids during embryonal life (which is due to the fusion of the pyramids in the pars superior and to a certain extent in the pars inferior) and in part to differences in the level at which the segmental arteries leave the renal artery

The course and origin of these segmental arteries may however vary still more when the arteries to single pyramids or groups of pyramids arise directly from the aorta These arteries are of importance from a roentgenologic as well as surgical point of view Attention will therefore first be given to their frequency regions of supply origin and course to the kidney

It has been stressed that the lower polar artery might be fairly wide and therefore supply a relatively large portion of the lower half of the kidney and that the vessel should therefore not be ligated in cases in which it causes obstruction at the uretero pelvic junction (WILDBOLZ 1931, DEMING 1949 O CONOR 1955 and others) McDONALD & KENNELLY (1959) showed that a supplementary artery usually supplied 25—50 % of the parenchyma

Clinical angiographic studies — A thorough search of the literature failed to reveal any roentgen anatomic studies of the fields of supply and relative frequency of supplementary arteries It has only been stated that selective catheterization of a kidney with multiple arteries is insufficient from a roentgenologic point of view because not all of the renal parenchyma will be filled with contrast medium (EDSMAN 1957) and thus the unfilled region may be mistaken as a possible sign of tumour (EDHOLM & SELDINGER 1956)

The caliber of the renal artery varies in proportion with the amount of functioning parenchyma (DOSS 1947 IDBOHRN 1954 1956 and others) This also holds for the supplementary artery EDSMAN (1957) found that in 20 % of kidneys with multiple arteries the supplementary artery was of the same width as the main renal artery

ORIGIN AND COURSE OF SUPPLEMENTARY ARTERIES

Autopsy studies — As a rule the supplementary arteries originate from the aorta at a level close to that of the main renal artery but sometimes far caudal to the latter SELDOWITSCH (1909) found that the supplementary artery never originated more than 105 mm distal to the main renal artery HELLSTROM (1928) measured the maximum distance as 70 mm ANSON RICHARDSON & MINEAR (1936) found the minimum distance between the arteries to be 7 mm and the maximum 89 mm They found that the supplementary artery left the aorta within 10 mm of the main renal artery in 50 % and within 40 mm in 60 % which agreed with the findings of SELDOWITSCH MELKONIAN (1954) judged the level of origin of the arteries in relation to the origin of the superior mesenteric artery as well as to the distance between multiple arteries The maximum distance between the origin of the main renal artery and a supplementary artery arising cranially to it was 38 mm

The supplementary arteries may run together with the main renal artery to the hilum or separately to the hilum or directly to the parenchyma depending on the distance between the origin of the main renal artery and that of the supplementary artery (GRAVES 1956)

Clinical angiographic studies — EDSMAN (1957) found that the supplementary arteries arose both cranially and caudally to the origin of the main renal

artery running to the upper renal pole in 30 % and to the lower pole in 21 %. ALBARRAN (1909) found supplementary arteries running to the lower pole to be more common. SELDOWITSCH (1909) described an extrahilar vessel running to the upper pole in 9 (17 %) of 53 kidneys and to the lower pole in 5 (9 %) while in 84 % of the total kidneys the supplementary arteries entered the hilum. From his fairly thorough case reports it is also possible to assess the frequency of arteries to the lower pole. In 55 % of the kidneys with multiple arteries a supplementary artery supplied the lower pole. EISENDRATH & STRAUSS (1910) whose material consisted of 28 kidneys with multiple arteries found a supplementary artery to run to the upper pole in 18 % and to the lower pole in 29 %. EISENDRATH (1920) regarded hilar vessels as normal and therefore recorded polar arteries as supplementary. In 45 kidneys with supplementary vessels arteries ran to the upper pole in 13 (29 %) and to the lower pole in 32 (71 %). HELLSTROM (1928) stressed the surgical importance of supplementary arteries and of 53 kidneys with multiple arteries he found a vessel to run to the upper pole in 26 4 % and to the lower pole in 9 4 % while in 81 1 % of the total kidneys the supplementary arteries entered the hilum. BERGENDAL (1936) whose material consisted of 46 kidneys with multiple arteries found the supplementary artery to run to the upper pole in 19 6 % and to the lower pole in 6 5 % while in 80 5 % of his kidneys the supplementary arteries entered the hilum. WEINSTEIN COUNTISS & DERBES (1940) found that of 192 kidneys with multiple arteries supplementary arteries ran to the upper pole in 47 % and to the lower pole in 68 %. The frequency exceeds 100 % because in some of the kidneys there were more than one supplementary artery.

Like the renal artery the supplementary arteries are end arteries. As early as 1901 KOLSTER pointed out that the vessels retained their segmentation even when the kidney was supplied by more than one renal artery. At operation for hydronephrosis due to supplementary lower polar arteries the latter have formerly been ligated often with good results (BERGENDAL 1936 HECKENBACH 1939 ENGEL 1951 and others). Sometimes such ligation has been followed by necrosis in the field of supply of the ligated vessel (PATCH 1929 WILDBOLZ 1931 DEMING 1949 O CONOR 1955 and others).

On the basis of corrosion preparations GRAVES (1954 1956) found that the supplementary arteries were segmental arteries of relatively proximal origin. He thus found that the ventral and dorsal middle segments of the kidney and the apical and lower polar segments were supplied solely by the supplementary arteries. He considered that supplementary arteries ran more frequently to the lower pole because the lower polar artery is the first to leave the renal artery in 63 % of normals.

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artery, but more often caudal When both the ipsilateral renal arteries were equally wide, he considered the upper one as being the main artery, because it originated at the same level as a normal (single) renal artery

SUMMARY

Several investigators have studied multiple renal arteries from an anatomical as well as surgical point of view Differences in the frequencies of multiple arteries given by many authors are due to some extent to differences in nomenclature Anatomic investigations have shown the occurrence of multiple arteries in 25—30 % of all kidneys

GRAVES showed that the supplementary arteries were segmental The relative frequency of these vessels has been classed according to their hilar or extra hilar course to the pole, but no previous attempts have been made to determine if the hilar vessels had a polar field of supply No systematic anatomical examinations have been made of the fields of supply of the supplementary arteries

Although clinical angiographic investigations have been made of the frequency of multiple arteries no endeavours have been made to chart the topography and field of supply of supplementary arteries In view of relatively recent advances in clinical angiography, especially selective renal angiography, detailed knowledge of the vascular pattern and fields of supply of multiple arteries is more necessary now than formerly

AUTHOR'S INVESTIGATIONS

MATERIAL AND METHODS

The present material consisted of 369 patients exam[illegible] angiography Of these, 73 were examined by unilateral se[illegible] tion, while in 8 patients both kidneys were studied sep[illegible] renal angiography Of the 89 kidneys studied by the [illegible] were found to have multiple arteries, and for this reas[illegible] afterwards studied by aortic renal angiography

In the evaluation of the topography and frequency of [illegible] those kidneys were excluded which showed signs of fus[illegible] In addition, those kidneys were rejected in which the [illegible] be studied completely This left a total of 638 kidne[illegible]

The origin, course, and field of supply of the [illegible] 142 kidneys could be seen in detail In the analysis [illegible] such vessels could not be classified as hilar or p[illegible] HELLSTROM (1928) and others It was often imposs[illegible] artery entered the hilum or ran directly to the paren[illegible] therefore named according to the pyramids they sup[illegible] thus gives information not only of the field of supp[illegible] of the vessel which is directly proportional to the [illegible] it supplies

As a rule the caliber of the supplementary arter[illegible] the main renal artery When both arteries were of [illegible] that supplied *inter alia* the 3 5 ventral pyramid [illegible] artery, because in the investigation of kidneys [illegible] the vessel to pyr 3–4(–5) V was the direct contin[illegible] which was in turn a continuation of the renal art[illegible]

In addition to the clinical material, contra[illegible] 34 kidneys (17 pairs) removed at autopsy (for [illegible]

Table 9 Frequency of multiple arteries in 638 kidneys in the clinical angiographic material

	1 artery	*2 arteries*	*3 arteries*	*4 arteries*	Total
Right	241	65	4	0	310
Left	245	79	3	1	328
Total	486	144	7	1	638
Per cent	76 2	22 6	1 1	0 1	

RESULTS

FREQUENCY OF MULTIPLE ARTERIES

Of 638 kidneys 152 (23 8 %) had multiple arteries [310 right kidneys and 328 left of which 69 (22 3 %) and 83 (25 3 %) *respectively had multiple arteries*] (Table 9)

Obstructive changes in the uretero pelvic junction causing hydronephrosis were seen in 64 kidneys Of these 33 had multiple arteries (51 6 %) If these 64 kidneys are excluded from the series it will leave a total of 574 kidneys of which 119 (20 7 %) have multiple arteries

In the present autopsy material (34 kidneys without hydronephrosis) 10 (29 4 %) were found to have supplementary arteries

FIELDS OF SUPPLY, TOPOGRAPHY AND RELATIVE FREQUENCY OF SUPPLEMENTARY ARTERIES

The origin course and field of supply of supplementary arteries to 142 kidneys were traced (clinical renal angiography) Eight of these kidneys had more than one supplementary artery Of the 142 kidneys 32 were hydronephrotic

Of 134 kidneys in which one supplementary artery was observed the latter supplied pyramids in the pars inferior in 95 (70 9 %) In 18 kidneys (13 4 %) it supplied pyramids in the pyr 1 2 V D segment and in 14 (10 5 %) pyramids within the field of supply of the dorsal artery In the remaining 7 kidneys (5 2 %) the supplementary artery supplied pyramids in the ventral mid portion of the kidney (pyr 3 4 5 V) (Table 10) In the 8 kidneys with more than one supplementary artery *all of the vessels were ordinary segmental* arteries

In the autopsy series of 10 kidneys with multiple arteries 6 had 1 supple

Table 10. Number and types of supplementary arteries in the clinical and autopsy series

Segments supplied	Number of supplementary arteries							
	Living subjects				Cadavers			
	1	2	3	Total	1	2	3	Total
Pyr. 1–2 VD	18	1	1	20	3	2	0	5
Pyr. 3–5 V	7	1	0	8	0	1	0	1
Pyr. 6–7 VD	95	7	1	103	2	4	0	6
Pyr. 3–5 D	14	5	1	20	1	1	0	2
Total number of kidneys	134	7	1	142	6	4	0	10

Table 11. Varying field of supply of supplementary arteries to pyr. 1–2 VD in the clinical and autopsy series

Material	<1 V	(1–)2 V	(1–)2 D	1–3 V	1–2 VD	1–3 VD	Total
Clinical	—	11	5	2	1	1	20
Autopsy	2	3	—	—	—	—	5
	2	14	5	2	1	1	25

mentary artery and 4 had 2. There, too, the segmental supply of the arteries was apparent (Table 10).

Pyr. 1–2 VD. — Supplementary arteries to this segment were demonstrated *in 20 out of 142 kidneys (14.1 %). The supplementary artery* was usually narrow and supplied one or two pyramids. The artery usually ran to the upper part of the pars superior and supplied pyr. (1–)2 V or rarely (1–)2 D (Fig. 24). Only in 1 case did the supplementary artery supply pyr. 1–3 VD (Table 11).

In 5 autopsy specimens supplementary arteries were found supplying ventral pyramids in pyr. 1–2 VD segment (Table 11). In 2 kidneys these vessels originated together with the capsular arteries (Fig. 25) from the aorta and supplied only part of a single pyramid.

Pyr. 3–5 V. — In 8 (5.6 %) of the 142 kidneys the supplementary artery ran to pyr. 3–5 V. In addition there were 3 kidneys in which pyr. 3 V was supplied by a branch of the supplementary artery to pyr. 1–2 VD (Table 11).

In all of these kidneys the supplementary artery was smaller in diameter than the main renal artery. In one case not included in this group the kidney was supplied by 4 multiple arteries. The artery to pyr. 3–5 V in this case was

Fig. 24. Aortic renal angiogram. Observe supplementary artery to pyr. 1-2 V of left kidney. R. sup. pyr. 1-2 V arises early from the renal artery to right kidney.

of the same caliber as the other 3, so that this was taken as the main renal artery because it originated at the same level as the contralateral main renal artery. In 2 kidneys the supplementary artery supplied only pyr. 3-4(-5) V (Fig. 20), while in 4 it supplied also the pyr. 1-2 V.

Pyr. 5 V was supplied alternatively by the artery running to pyr. 3-4 V as well as by that extending to pars inferior, except in 2 kidneys in which pyr. 5 V was supplied separately by a supplementary artery arising from the aorta. In one of the kidneys the vessel also supplied pyr. 6 V (Fig. 27).

Only in 1 of the autopsy specimens did a supplementary artery run to the pyr. 3-5 V segment. In this case it supplied only pyr. 5 V.

Pyr. 3-5 D. — In 20 (14.1 %) of the 142 kidneys the dorsal artery was supplementary. Its field of supply varied in the same way as in kidneys supplied by a single artery. *As a rule, the supplementary artery thus represented the* entire dorsal artery, so that its field of supply extended from the pars intermedia in both cranial and caudal direction. In 17 kidneys the dorsal supple-

Fig. 25. Autopsy specimen. Both kidneys are supplied by a supplementary artery to pyr. 1 V. The artery divides into two branches of equal calibre, one supplying the renal parenchyma and one the fatty capsule.

mentary artery supplied not only pyr. 4 5 D but also pyr. 3 D and in 12 the entire dorsal portion of pars superior. In 5 of these 12 kidneys pyr. 1 2 V was also supplied by this vessel (Fig. 28). Caudally the field of supply often extended to include pyr. 6 D (7 kidneys), less commonly pyr. 6 7 D (3 kidneys).

Occasionally there was more than one dorsal artery, one from the main renal artery and one supplementary, which then supplied one or more dorsal pyramids. The supplementary dorsal artery supplied only pyr. 5 D in 2 kidneys and pyr. 4 5 D in one (Fig. 29). A further 5 kidneys had 2 dorsal arteries each, one arising from the main renal artery with an ordinary field of supply, and a second with a supplementary dorsal artery nourishing only the dorsal pyramids of the pars inferior (Fig. 30). These 5 kidneys are included in the group of supplementary arteries to Pyr. 6 7 V D.

The autopsy material included two specimens in which the dorsal artery represented the supplementary artery, and in both cases it supplied pyr. 1 5 D.

Pyr. 6 7 V D. — Of 134 kidneys with only one supplementary artery, the

Fig 4 Aortic renal angiogram Observe supplementary artery to pyr 1-2 V of left kidney R sup pyr 1-2 V arises early from the renal artery to right kidney

of the same caliber as the other 3 so that this was taken as the main renal artery because it originated at the same level as the contralateral main renal artery In 2 kidneys the supplementary artery supplied only pyr 3-4(-5) V (Fig 20) while in 4 it supplied also the pyr 1-2 V

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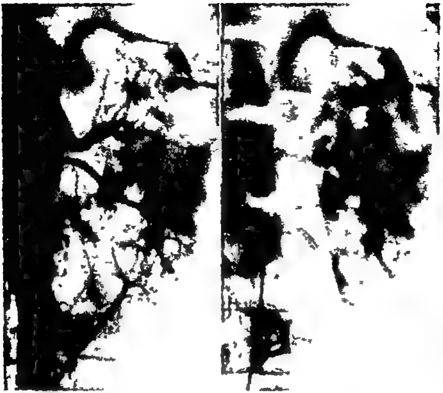


a b

Fig. 27. Aortic renal angiogram. Normal topography of left kidney.

a Arterial phase. Left kidney supplied by multiple arteries: (1) a. renalis pyr. 1–4 V, 1–6 D; (2) a. ventr. pyr. 5–6 V (→) and (3) a. inf. pyr. 7 V D (→). The artery to the lower pole originates 110 mm caudal to the main artery and has a steeply ascending straight extrahilar course.

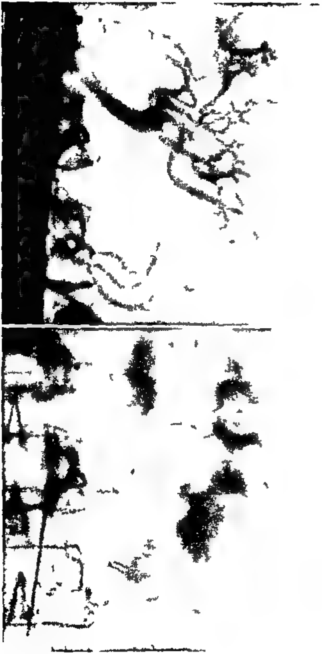
b Nephrographic phase. Tip of the catheter is close to the origin of the a. ventr. pyr. 5–6 V; there is therefore a heavy deposit of contrast medium in the cortex and spasm in the artery with demonstration of pyr. [illegible] 6 V as a consequence.

pyramids of the pars inferior were supplied in 93. In the [illegible] kidneys with more than one supplementary artery one of these constantly supplied the pyramids in the lower renal pole (Figs. 27–29).

In 88 kidneys the field of supply of the supplementary artery could be seen adequately for study. The vessel had essentially the same field of supply as the artery to pars inferior in kidneys with a single renal artery. Differences

Fig. 26a, b. Selective angiogram (left kidney). Arteries to pyr. 3–4 V are missing and there is a corresponding defect in the nephrogram

c Aortic renal angiogram. A supplementary artery supplying pyr. 3–4 V (→) arises 8 mm cranial to the main renal artery



d

e

Fig. 29

a

b

F g °8 Selective (*a–c*) an l aort c (*l e*) r nal ang gram (left ki lney)

a–b Arterial pl as n frontal (*a*) an l obl q e (*b*) v w Only tl e ventral artery (ma n artery = a ver tr j yr 3 7 V 6 D) s catl eter z d

c Nepl rograp l c pl ase V acc m il t on of contrast in upper an l dorsal part of kidney except f r pars infer r Obs rve characteristic irregular marg n in tl upper part of k lney

l–e Tl e s pplementary l rsal artery is ow f lle l (a dors n r 1 2 V 1 5 D)

F g 5

a

Fig. 9a Aort. renal ang ogram The ma n artery an l two sup plementary arter es supp ly th e malrotated r ght k dney a renal s supp y ng pyr 1 3 D 1 5 V a lors pyr 4 5 D and a nf pyr 6–7 V D Th e two s pplementary arter es arise 65 an l 117 mm cau dal to or g n of ma n artery Both arter es ha e a steeply ascen l ng co rse and seem be stra ghtened poss bly as a s gn that they l ave prevente l th e normal rotat on of the k dney The lower polar a tery stems from th e l ac artery

b–c Urogram an l d agrammat c s per mpos t on of arter ogram sh ow ng rotat on and the relat on between th e pel s an l th e vasc lar supply

a

b

Fig 3

were occasionally observed in single kidneys because the supplementary artery sometimes supplied only dorsal pyramids (Fig 30) and occasionally only one pyramid (Fig 31) The field of supply of the supplementary artery varied with the origin from the aorta In the group (70 kidneys) in which the vessel originated within 70 mm of the main renal artery it supplied the entire pars inferior (pyr 6–7 V D) in 67 % (47/70) and in 9 of these kidneys also the pyramids in pars intermedia usually pyr 5 V. The number of pyramids supplied in this group varied between 1 and 6 usually 4 pyramids (pyr 6–7 V D)

In the group (18 kidneys) in which the supplementary artery arose more than 70 mm distal to the main renal artery the same number of pyramids were supplied as in the previous group The entire pairs of pyramids (pyr 7 V D 6–7 V D 5 7 V D) were supplied in 83 % (15/18 kidneys) as against 57 %


a
b
c
d

Fig. 30. Malrotated right kidney.

a Selective angiogram, arterial phase. Frontal view. Vessels in dorsal part of lower pole are missing.
b Aortic renal angiogram, arterial phase. Frontal view. Artery to lower pole supplies pyr. 5–7 D and arises 90 mm from the origin of the main artery.
c Selective angiogram, nephrographic phase. Oblique view. Irregularly outlined defect corresponding to pyr. 5–7 D.
d Aortic renal angiogram, nephrographic phase. Frontal view.
e Urogram showing rotated intrarenal pelvis.

(40/70 kidneys) of the larger group in which the artery originated within 70 mm of the main renal artery. In kidneys where not pairs of pyramids were supplied in the larger group it usually supplied ventral pyramids, in the other group mainly dorsal pyramids (in 2 cases pyr. 5–7 D, in 1 pyr. 5–7 D, 6–7 V).

The autopsy series included 6 kidneys with a supplementary artery to pyr. 6–7 VD. In all of them the supplementary artery originated within 70

Fig 31

mm of the main renal artery and its field of supply was equal to that found in corresponding angiograms of living subjects Four kidneys had 2 supplementary arteries one of these ran to pyramids in the lower pole while the other supplied pyramids within the pyr 1–2 V D 3 5 V or 3–5 D segment (Table 10)

ORIGIN AND COURSE OF SUPPLEMENTARY ARTERIES

Pyr 1 2 V D — The artery to this segment originated either at the level of the main renal artery or within 17 mm cranial to it It then ran a slightly ascending course to the upper pole of the kidney usually directly into the parenchyma without passing through the hilum The upper polar artery in the contra lateral kidney often also departed early from the renal artery (Fig 24)

Pyr 3–5 V — In 2 kidneys the artery to this segment arose caudally to the main renal artery In both pyr 5 V was supplied separately (Fig 27) In the other 6 kidneys the supplementary artery ran cranially to the main artery within 10 mm and parallel to it (Fig 26)

Pyr 3–5 D — In 12 kidneys the supplementary dorsal artery arose from the aorta with a maximum of 5 mm from the main renal artery (ventral artery) In one fourth of the kidneys the supplementary dorsal artery arose cranial thereto at most 12 mm from the main renal artery and in the rest caudal to the main artery In 2 kidneys the supplementary dorsal artery deviated considerably from the remainder of kidneys in that the dorsal artery arose distally from the aorta (65 and 82 mm respectively) below the origin of the main artery and ran a steeply ascending course to the kidney (Fig 29) In the remaining cases the dorsal artery ran parallel to the ventral artery and the intrarenal patterns of the two vessels could be very similar (Fig 32)

As in kidneys with a single artery the dorsal artery sometimes arose from the lower polar artery This was observed in 4 instances the vessel supplying the dorsal pyramids and the pyramids in the pars inferior being supplied by the main renal artery

Pyr 6 7 V D — Of the 103 kidneys examined in living subjects with supplementary arteries to pars inferior the origin of the supplementary artery could be evaluated in 101 Most of these arteries originated from the aorta quite close to the main renal artery (Figs 33 and 36 right) in 50 kidneys within 10 mm of the renal artery In 7 of these kidneys it arose cranial to the main

Fig 31 Aortic renal angiogram A narrow supplementary artery emerging from the aorta a few millimetres below origin of main renal artery The supplementary artery runs parallel to the main artery and supplies only one pyramid (pyr 6 D)

mm of the main renal artery and its field of supply was equal to that found in corresponding angiograms of living subjects. Four kidneys had 2 supplementary arteries; one of these ran to pyramids in the lower pole, while the other supplied pyramids within the pyr. 1–2 VD, 3–5 V or 3–5 D segment (Table 10).

ORIGIN AND COURSE OF SUPPLEMENTARY ARTERIES

Pyr. 1–2 VD. — The artery to this segment originated either at the level of the main renal artery or within 17 mm cranial to it. It then ran a slightly ascending course to the upper pole of the kidney, usually directly into the parenchyma without passing through the hilum. The upper polar artery in the contra lateral kidney often also departed early from the renal artery (Fig. 24).

Pyr. 3–5 V. — In 2 kidneys the artery to this segment arose caudally to the main renal artery. In both, pyr. 5 V was supplied separately (Fig. 27). In the other 6 kidneys the supplementary artery ran cranially to the main artery within 10 mm and parallel to it (Fig. 26).

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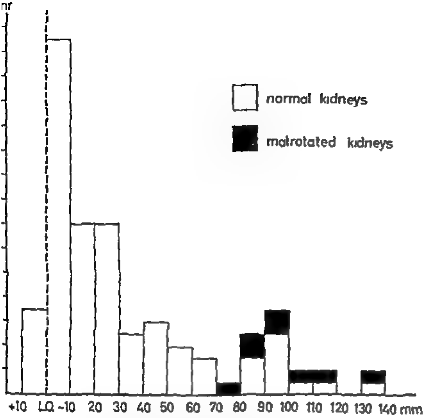
Fig. 31. Aortic renal angiogram. A narrow supplementary artery stemming from the aorta a few millimeters below origin of main renal artery. The supplementary artery runs parallel to the main artery and supplies only one pyramid (pyr. 6 D).

Fig 3 Aortic renal angiogram Course and ramification of supplementary dorsal artery (→) resemble that of ventral artery (1) a dors pyr 1 2 V 1 5 D (2) a ventr pyr 3 7 V 6 7 D

renal artery at most 7 mm (Fig 34) In 19 kidneys the distance was 20—30 mm in 10 40—59 mm and in 4 60—79 mm The number of supplementary arteries thus decreased with increasing distance from the origin of the main artery Caudally over 80 mm however the number again increased so that in 18 kidneys the origin of supplementary arteries to the lower pole was distal to this level (80—99 mm from origin of renal artery in 12 cases 100—119 mm in 4 and greater than 120 mm in 2 kidneys) The greatest distance between the main artery and the supplementary artery was 135 mm

The course of the supplementary artery to the kidney varied with its origin from the aorta the position of the kidney and the size of the kidney Like



41 Variations in distance between origin of supplementary artery to pyr 6–7 V D and main renal artery

L O = Level of origin of the main artery

nd — denote origin of the supplementary artery cranially and caudally respectively, to the main artery

main renal artery, the supplementary artery sometimes ran a descending ırse, sometimes horizontal, and sometimes ascending

f the supplementary artery (lower polar artery) arose above the origin of main artery or within 40 mm distal thereto, *it almost always ran a des* ding course The vessel often ran a horizontal course in the beginning, allel to the main artery especially if the two vessels originated at roughly same level (Fig 31) If the supplementary artery arose at a more caudal

Fig 34 Aortic renal angiogram Supplementary lower polar artery (→) originates from the aorta 7 mm cranial to the main artery and has a descending course

level it first ran cranially and then followed the main artery to the neighbourhood of the hilum Within or just before the hilum the vessel would course to the lower pole as an ordinary segmental artery (Fig 35)

The course of the supplementary lower polar artery in the hilum and sinus was latero caudally but owing to its more proximal origin it was less steep than r ventr pyr 6–7 VD when the latter arose from the ventral artery

The course of the segmental artery to the kidney was sometimes horizontal when it originated 40—70 mm from the main renal artery, but usually it was ascending Of the latter course two variants were found the vessel running either in a wide arc up to the lower part of the hilum (Fig 36, left) or running a straight cranio lateral course (Fig 37)

All of the supplementary arteries stemming from the aorta above the origin

Fig 35 Aortic renal angiogram Supplementary lower polar artery arises 12 mm caudal to the origin of the main artery turns cranially and runs parallel to the latter and then outside the hilum runs caudolaterally like an ordinary segmental artery

of the renal artery or within 70 mm caudal to it entered the kidney at the level of the hilum and the origin was never below the middle of L III

In a total of 19 kidneys the supplementary segmental artery departed from the aorta more than 70 mm distal to the main renal artery In 3 of these kidneys the artery arose from the iliac artery (Fig 29) and in one from the middle sacral artery (Fig 38) In 4 the supplementary artery ran a horizontal or almost horizontal course (Figs 30 38 39) In 3 of these the kidney was mal rotated while the fourth showed a double kidney pelvis the lower portion being intrarenal (Fig 39) In these 4 kidneys there was no true caudal dystopia although the lower pole of the kidney was low

The remaining 15 kidneys were situated at an ordinary level and the supple mentary artery ran an ascending course to the lower pole of the kidney The

Fig 34 Aortic renal angiogram Supplementary lower polar artery (→) originates from the aorta 7 mm cranial to the main artery and has a descending course

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All of the supplementary arteries stemming from the aorta above the origin

a b

Fig. 37a. Aortic renal angiogram. Supplementary lower polar artery originates 60 mm caudal to the origin of the main renal artery and has a straight cranio-lateral course to lower pole of the kidney.

b. Urogram. The pelvis is intrarenal.

DISCUSSION

FREQUENCY OF MULTIPLE ARTERIES

In order to facilitate comparison with investigations on record and the evaluation of the frequency of kidneys with multiple arteries, kidneys with abnormalities liable to increase this frequency were excluded. In clinical material dystopic kidneys, fused kidneys and hydronephrosis with obstruction at the uretero-pelvic junction are over-represented. Earlier investigators have shown that the supply to dystopic and fused kidneys differs from normal (YOUNG & THOMPSON 1903, GÉRARD 1905, ANITSCHKOW 1912, BELL 1950, EDSMAN 1957 and others) and that such kidneys are, as a rule, supplied by multiple arteries.

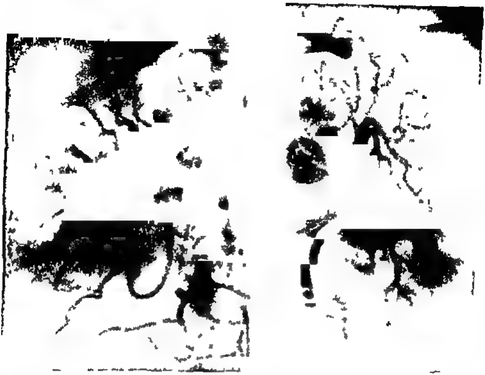
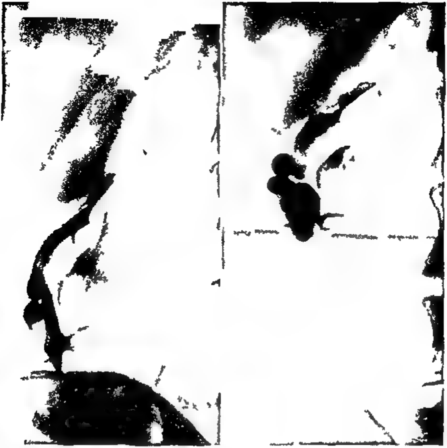


Fig 36 Aortic renal angiogram Supplementary lower polar artery to *left* kidney originates 40 mm from the main renal artery and runs in a wide arc cranially to the lower part of the renal hilum Supplementary *right* lower polar artery originates close to the main renal artery and has a tortuous course to the lower part of hilum

vessel also appeared to be stretched or straightened (Figs 27, 29, 40) In 2 patients the same appearance was seen on both sides (Fig 40) Of these kidneys 5 were obviously malrotated and 6 only slightly as judged by the superimposition of the confluence of the pelvis over the kidney ("intrarenal" pelvis)

Of the 19 kidneys in which the supplementary artery stemmed at a distance of *more than 70 mm from the main renal artery, it ran a completely or partly* extrahilar course in 13 and branched distally to L III (Figs 27, 29, 40) In the remaining 6 kidneys the supplementary artery was given off above the lower third of L III in one kidney



b c

Fig. 38b–c. Urogram. On displacement of kidney in cranial direction by abdominal compression the kidney will rotate still more because of the traction by the extral lar lower polar artery

pelvic junction in these 3 series taken together was 48 %, which is definitely higher than in a normal series.

After exclusion of the above mentioned kidneys the frequency of multiple arteries was 20.7 %, a figure agreeing well with what EDSMAN (1957) found in an angiographic material (20 %). EDSMAN reported a good correlation between his figures and those found in earlier anatomic investigations. It is striking however that the two angiographic investigations gave a frequency of about


a

ig 38a Malrotated ptotic kidney Aortic renal angiogram Supplementary lower olar artery originates from middle sacral artery 75 mm distal to the level of origin of main renal artery

ANDERSON (1953) (72 operative specimens) and EDSMAN (1957) (angiograms f 71 kidneys) showed that multiple arteries are much more common in the resence of hydronephrosis with obstruction at the uretero pelvic junction hese authors found multiple arteries in 55 % of kidneys and 38 % respectively ompared with 51 % (64 kidneys) in the present material This relatively rge difference in frequency might be due to the smallness of the 3 series he overall frequency of multiple arteries with obstruction of the uretero

Fig 39c Urogram shows the double kidney pelvis and the intrarenal lower kidney pelvis

In the aortic angiographic series the tip of the catheter was placed at the level of origin of the renal arteries and contrast medium was injected in retrograde direction so that any arteries originating cranially to the main renal artery might not be properly filled with contrast medium If this happened characteristic segmental arteries would not show up but this feature was not observed in the present material nor was any part of the kidney missing in the nephrogram

As will be apparent later arteries to pyr 1 2 V D and supplying less than one renculus do not show up in the film owing to the smallness of the lumen and the relatively low density of contrast Therefore arteries to the segment

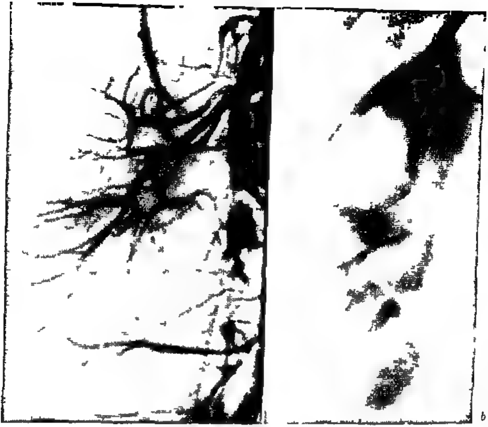
a  b

Fig 39a b Aortic renal angiogram of a long double kidney Supplementary lower polar artery arises 95 mm distal to origin of main renal artery and has a horizontal course to hilum

20 % while Hou Jensen (1930) in a compilation of observations in autopsy series consisting of a total of more than 2 500 kidneys reported 22 4 % and later investigators gave still higher frequencies The total material on record (4 118 kidneys) showed a frequency of 26 0 % The frequency found in the present autopsy series was also higher 29 4 % The present autopsy series included no cases of hydronephrosis In earlier anatomic studies cases of hydronephrosis were not excluded but such cases are probably so rare that they will hardly influence the results

The discrepancy between clinical and post mortem studies can be explained by clinical angiography failing to demonstrate all supplementary renal arteries

Fig 40b Urogram shows rotated pelvis On the right side hilum is directed ventrally on the left laterally

supplementary artery rarely supplied the entire segment On the other hand a supplementary artery sometimes supplied more than one segment as in kidneys with a single renal artery

It appears that the relative frequencies of different supplementary arteries have hitherto not been studied in angiograms of living subjects or of cadavers GRAVES (1956 1957) simply stated that supplementary arteries ran to the lower pole more frequently than to other segments On the other hand various examiners have studied the frequency of supplementary polar arteries (extra hilar arteries) at autopsy in relation to that of supplementary arteries entering the hilum (Table 12)

This applies in particular to the findings of WEINSTEIN, COUNTISS & DERBES (1940) which deviated widely from those of other authors. They found supplementary upper polar arteries in 47 %, while other authors found about 24 %. The frequency found by the angiograms in kidneys of cadavers in the present study agreed fairly well with the figures given by WEINSTEIN, COUNTISS & DERBES, while the *incidence found in the clinical angiographic series* was more than 30 % lower. The frequency with which supplementary upper polar arteries was found in the present clinical series was also lower than that found by other authors in the dissecting room despite inclusion in the present material of all arteries to pyr. 1, 2 V D. This included those cases in which the artery passed through the hilum to the segment. However, the supplementary arteries running through the hilum appear to represent a very small percentage since such vessels were never seen in the present autopsy series. Pyr. 3 V D also belongs to the upper pole, but in no instance was any supplementary artery seen to run only to pyr. 3 V or D.

HYRTL (1872) pointed out that the capsular artery coursing in a cranial direction from the renal artery occasionally supplied small regions of the renal parenchyma. WEINSTEIN, COUNTISS & DERBES (1940) found that two thirds of the supplementary arteries to the upper pole arose from suprarenal arteries. ANSON, CAULDWELL, PICK & BEATON (1947, 1948) studied the inferior phrenic artery and the suprarenal arteries at autopsy. They found that these vessels could give off fine branches supplying both the fatty capsule around the upper renal pole and the renal parenchyma.

The reason why these vessels escaped demonstration in living subjects was found on analysis of the autopsy series. In 5 post mortem specimens the ventral pyramids in the segment under discussion were supplied by a supplementary artery. In all of them the artery gave off a capsular artery and in 2 kidneys these two vessels were of the same width after division (Fig. 25). In aortic renal angiograms the capsular and pelvic arteries are not often seen because of their small diameter and the relatively low density of contrast medium. Since these small supplementary arteries to the pyramids in the upper renal pole are not wider than the capsular arteries, it is obvious that they do not appear in the angiogram either.

This discrepancy in the supply of the upper pole between the clinical and the autopsy series explains the lower frequency of multiple arteries seen in clinical angiograms. Thus in the present clinical material multiple arteries were seen in about 20 % as against 28 % in compilations given by HELLSTRÖM (1928) and BERGENDAL (1936) for post mortem studies, i.e. a difference of about 8 %, which corresponds to the difference in the supply to the upper renal pole in the 2 series (10 %). WEINSTEIN, COUNTISS & DERBES (1940)

Table 12. Relative frequency of different types of supplementary arteries in previous anatomic investigations compared with the present angiographic study of the clinical series and specimens from cadavers

Author	Supplementary								Number of kidneys with multiple arteries
	upper polar artery		lower polar artery		artery to 3–5 V		artery to 3 5 D		
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	
Thompson (1891)	29	29.3	21	21.2					99
Schlowitsch (1909)	9	17.0	29	54.7					[illegible]
Hellstrom (1928)	14	26.4	5	9.4					53
Bergendal (1936)	9	19.6	3	6.5					46
Weinstein, Countiss and Derbes (1940)	90	46.9	130	67.7					192
Boijsen angiograms (clinical)	20	14.1	103	72.5*	8	5.6	20	14.1	142
Boijsen angiograms (post mortem)	5	50	6	60	1	10	2	20	10

* Extrahilar arteries to pars inferior in 13 kidneys (9.1 %)

Pyr. 1–2 V D segment. — In the 20 kidneys in which the supplementary artery to pyr. 1–2 V D segment was demonstrated by clinical angiograms it was found to supply the two ventral pyramids in the majority of cases, this part corresponding to the segment GRAVES (1954) called apical. In one fourth of the kidneys, however, the pyr. 1 2 D segment was supplied by the supplementary artery and then the apical segment was represented by the dorsal pyramids. *Only in two kidneys was the entire pyr. 1–2 V D supplied by the supplementary artery* (Tables 11 and 13).

Of the 142 kidneys in the clinical angiographic series with multiple arteries 14.1 % had supplementary arteries running to pyr. 1 2 V D segment. In the autopsy series the corresponding frequency was 50 % (Tables 10 and 12).

There was thus a considerable discrepancy between the frequency of supplementary arteries to pyr. 1 2 V D segment as seen in angiograms of living subjects and cadavers. *This difference might, however, be ascribed to the* small number of kidneys (10) having multiple arteries in the autopsy series.

A compilation of earlier autopsy studies, however, shows that of all kidneys with multiple arteries supplementary arteries supply the upper pole in 34 % (151/443, Table 12). Table 12 shows a considerable difference between the results found by earlier investigators concerning the supply to the upper pole

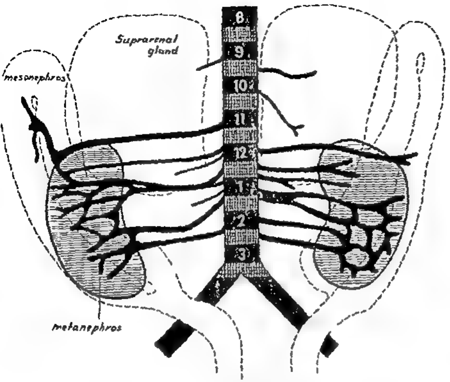


Fig 41 Diagram of the *rete arteriosum urogenitale* formed by arteries supplying mesonephros and later metanephros in early embryonal life (after FELIX 1911)

to have a supplementary dorsal artery The distribution of such supplementary dorsal arteries in the parenchyma varied in the same way as if the vessel arose from the renal artery The primary field of supply of the dorsal artery thus included all dorsal pyramids just as the ventral artery supplied the ventral pyramids In embryonal life there is a well developed *rete arteriosum* around the aorta and the kidney (FELIX 1911 BREMER 1915) (Fig 41) It is the degeneration of certain vessels and the persistence of others that account for the variations in the field of supply of the ventral and dorsal arteries respectively in the adult The pars intermedia is the centre of a field of supply of the dorsal artery that extends a variable distance in both a cranial and caudal direction Since the dorsal artery usually branches from the renal artery and continues undivided into the renal sinus this might very well explain why supplementary

Table 13 Variations in field of supply of different types of supplementary arteries (clinical material)

Supplementary arteries to	Number of pyramids supplied								Total number of kidneys	Remarks
	1	2	3	4	5	6	7	8		
Pyr 1–2 VD	1	15	[illegible]	1	—	1	—	—	20	
Pyr 3 5 V	1	2	1	2	2	—	—	—	8	
Pyr 3 5 D	2	1	2	2	6	—	5	2	20	
Pyr 6–7 VD	3	9	11	38	8	1	—	—	70	Departs within 70 mm from main artery
	—	7	2	7	1	—	—	1	18	*Departs more than 70 mm from main artery*

found multiple arteries in about 47 %, a figure much higher than that given by other investigators but nevertheless in accord with the high frequency of supplementary arteries to the upper pole in their series Since two thirds of these supplementary arteries branched from suprarenal arteries they were very small in diameter and not demonstrable in the clinical angiograms This inability to detect narrow vessels to the upper pole in the clinical angiograms explains the *relatively low frequency of kidneys with more than one supplementary* artery in the material

Pyr 3–5 V — In 5 6 % of all kidneys with multiple arteries the angiograms showed supplementary arteries which supplied mainly renculi in that segment No separate supply to pyr 3 V and 4 V was observed, both pyramids usually being supplied by the supplementary artery (Fig 26), which sometimes extended cranially so that it supplied also pyr 1–2 V The pattern of the supplementary artery thus resembled that of the ventral artery in kidneys with a single renal artery where the vessel to the lower pole arose early from the renal artery (Figs 14 16) The supplementary artery was also obviously a segmental artery in these cases In the kidneys with a single artery it was found that pyr 5 V was sometimes supplied by the artery running to pyr 3–4 V or to pyr 6–7 VD, but occasionally the vessel arose separately from the renal artery (Fig 18) It was also found that pyr 5 V was sometimes supplied separately by a supplementary renal artery or by a supplementary artery to the lower pole or to pyr 3–4 V The number of pyramids supplied by the artery running to pyr 3–5 V segment varied between 1 and 5 (Table 13)

Pyr 3–5 D — In all the kidneys with multiple arteries 14 1 % were found

dorsal branches to 1 or 2 pyramids only are uncommon when compared with supplementary branches from the ventral artery. On the other hand, since the dorsal artery leaves the renal artery as the first branch more frequently than other segmental arteries, it is understandable that it is frequently seen as a supplementary artery.

In accordance with the above findings the supplementary dorsal artery was found to supply 5–8 pyramids in two thirds of the kidneys and only occasionally 1–2 pyramids and then there was a further dorsal artery branching from the main renal artery (Table 13).

In 5 kidneys one or more dorsal pyramids in the pars inferior were supplied by a supplementary artery. These cases thus represented a variant of the dorsal artery but are included in the next group.

Pyr. 6–7 I D. — Of the entire series with multiple arteries the supplementary artery supplied the pars inferior in 72.5 %. This frequency is slightly higher than what has been found in autopsy series by SELDOWITSCH (1909), WEINSTEIN, COUNTISS & DERBES (1940). EISENDRATH (1920) found a supplementary artery to the lower renal pole in 71 %, but he had not included the supplementary arteries entering the hilum. GRAVES (1956) described the lower polar artery as being much more common than other supplementary arteries. It is difficult to judge from examination at autopsy which region is supplied by a given artery. HELLSTRÖM (1928) and BERGENDAL (1936) therefore content themselves with the determination of extra-hilar polar arteries, which they found in 9.4 % and 6.5 % respectively. In the present clinical angiographic series definite extrahilar arteries to pars inferior were found in [illegible] 1 %. (Table 12).

The fairly wide variation in the autopsy studies (Table 12) is due at least in part to the fact that some authors classified only definite extrahilar arteries as polar arteries (HELLSTRÖM 1928, BERGENDAL 1936) while others [illegible] lower polar supplementary arteries as ext[illegible] DERBES 1940) where[illegible] [illegible] ll the lower portion [illegible] specimens and of h[illegible] supply of the supplementary [illegible] it is always possible to determine [illegible] angiograms of autopsy [illegible] The higher frequency of supplementary arteries to pars inferior found in the angiograms of living subjects when compared with those of autopsy specimens (72.5 % as against 60 %) can be explained by the fact that the former group included also kidneys with hydronephrosis with obstruction at the uretero-pelvic junction. In such cases there was a definitely higher frequency of supplementary arteries to pars inferior.

The field of supply of the lower polar artery varied to a certain extent with the origin of the vessel from the aorta. This might be tentatively explained by

More likely is that all supplementary arteries near the main artery represent persisting mesonephric arteries. According to BROMAN (1908) and others these vessels degenerate in a cranio caudal direction so that the caudal most vessels will persist longest which implies that they have the greatest chances of persisting in adults. This means that the lowest renal segment (pyr 6–7 V D) is most likely to be supplied by supplementary arteries. An observation in support of this assumption is that one of these vessels always supplied the lower renal pole in all kidneys in the clinical and autopsy series with more than one supplementary artery.

The supplementary arteries to different segments arose from the aorta at different distances from the main renal artery. As a rule arteries to pyr 1 2 V D arose cranial to the main renal artery and those to pyr 6 7 V D distal thereto though occasionally cranial to the main renal artery. The supplementary dorsal artery usually arose at a level close to the origin of the main renal artery. In those kidneys in which only single dorsal pyramids were supplied by the dorsal artery the latter sometimes arose in a very distal segment of the aorta but there was then a wider dorsal artery from the main renal artery. Arteries to pyr 3–5 V usually arose cranial to the main renal artery close to its origin.

The course of the supplementary arteries varied with their origin from the aorta field of supply and position of the kidney. The supplementary dorsal artery and the artery to pyr 3 5 V most frequently ran parallel and close to the main renal artery while the artery to pyr 1 2 V D ran a more direct usually extra hilar course to the upper pole.

As to the origin and course of the supplementary artery to pars inferior the material could be divided into two groups namely vessels arising within 70 mm of the origin of the main renal artery and vessels branching later.

In those cases in which the artery arose within 70 mm of the main artery the origin was never below the middle of L III. These arteries represent persistent mesonephric arteries which have taken over the supply after the finish of the ascent of the kidney. This group was by far the largest and represented 81 % of all supplementary arteries to the pars inferior. In 50 % of all kidneys with a supplementary artery to the lower pole the vessel originated within 19 mm and in 68 % within 39 mm of the main renal artery. These figures are in good agreement with those found at autopsy (SELDOWITSCH 1909 ANSON RICHARDSON & MINEAR 1936). No correction was made for the radiographic enlargement this being irrelevant.

Within 40 mm from the main renal artery the lower polar artery often descended frequently in a common pedicle as in GRAVES (1956) material. The artery did not run caudo laterally until it approached the kidney as a

investigation to call the wider artery the main renal artery and the narrower the *supplementary artery*

The artery which *inter alia* supplied pyr 3–4V was the main artery the artery to that segment normally being a direct continuation of the ventral and the renal artery (Part I) EDSMAN s definition of the main renal artery as being the one *first to leave the aorta when multiple arteries were of equal* width was found to hold in the present material in all kidneys except 2 In one of these kidneys 4 arteries ran to the kidney and the arteries to pyr 1–2 VD (the one that left the aorta first) was of the same width as the others In the other kidney the dorsal *artery was a supplementary artery and de* parted 12 mm cranial to the ventral artery (main renal artery) both of the same caliber In these two kidneys the artery supplying *inter alia* pyr 3–4V arose at the level of the main renal artery to the contra lateral kidney

Understanding of the wide variation in the course of the multiple arteries requires knowledge of the embryology of the kidney During the ascent of the kidney it is supplied by arteries from the iliac artery and the middle sacral artery (JEIDELL 1911) Later new arteries from the aorta appear, while the lower ones atrophy (BREMER 1915) When the kidney has reached its final site a mesonephric artery situated at the level of the 21st aortic segment gives off an artery to the kidney (FRÉDÉRIC 1897, BROMAN 1911 and others) As a rule this artery takes over the entire supply of the kidney However the mesonephric arteries may reach down to the 23rd aortic segment (BROMAN 1908 FELIX 1911) (Fig 41) which may explain the supplementary arteries down to this segment *i e* down to the level of the middle of the L III Renal arteries distal to this represent vessels that arose during the ascent of the kidney but for some reason were not obliterated According to AREY (1954) the appearance of vascular anomalies is due among other things to the choice of unusual paths in the primitive vascular plexuses and the persistence of vessels normally obliterated

GRAVES (1956) believed that the reason why the lower polar artery was the most common *supplementary* artery was *because in 63 % of cases it de* parted from the renal artery as the first segmental vessel when the renal artery was single His assumption could not be confirmed in the present material because the dorsal artery was found to leave the renal artery as the first *branch much more frequently* [Part I 59 % (dorsal artery) and 20 % (lower polar artery)] In an earlier publication in 1954 GRAVES gave the same figure for the lower polar artery but then described it as arising from the ventral artery which coincided with the findings of the present investigation The higher frequency of the supplementary lower polar artery thus has nothing to do with its early origin in normal cases

when it was rotated ventrally According to these authors, the more abundant dorsal vascular supply contributed to the stronger growth of the dorsal renal parenchyma, so that the kidney appeared to be malrotated

The present investigations showed that the dorsal vessels were of importance not in the way believed by YOUNG & THOMPSON, but rather as a purely mechanical factor The supplementary lower polar arteries were stretched in malrotated kidneys In 3 kidneys the dorsal supply was predominant so that in 2 kidneys only dorsal pyramids (5–7 D Fig 30) were supplied and the third was supplied not only by the lower polar artery to pyr 6–7 VD, but also by a dorsal artery coming from below to pyr 4–5 D (Fig 29) In all of the other malrotated kidneys, the artery was extrahilar and supplied both the ventral and dorsal pyramids (Fig 40) The extrahilar dorsal branch which was situated medial in these cases, prevented further rotation of the kidney Sometimes the kidney rotated inwardly before the supplementary artery became taut, rotation then being incomplete with a so called intrarenal pelvis, i e the confluence of the pelvis was projected over the medial part of the parenchyma (Figs 37 and 39 lower renal pelvis)

These malrotated kidneys situated at normal level represent the only clear malrotations in the entire clinical angiographic material These observations thus prove that arteries persisting from the time of the ascent of the kidney prevent normal rotation This tightening up of the arteries during the ascent of the kidney can even cause outward rotation (Fig 40 left)

CONCLUSIONS

1) The supplementary arteries are segmental and correspond to branches of a single renal artery The importance of the segmental arteries being end arteries should not be underestimated from a roentgenologic or surgical point of view About 20 % of all kidneys were supplied by a supplementary artery large enough to be of diagnostic importance Selective angiography will show the presence of any supplementary arteries, both by the pattern of the intrarenal arteries and the distribution in the kidney and also by any defect in the nephrogram This is demonstrated best by examination of the kidney from more than one angle The supplementary arteries can supply a central portion of the kidney, i e within the region of the dorsal artery when no defect will be found in the nephrogram Detailed knowledge of roentgen anatomy, however, makes it possible to detect any absence of segmental arteries in the arterial phase in a single plane A defect in the angiogram due to lack of filling of a supplementary artery can be distinguished from a tumour because the defect produced by the former in the nephrogram is of characteristically irregular

segmental artery which had originated in the renal artery or ventral artery. Also within this range 40—70 mm from the main artery the vessel ran into the lower part of the hilum but no longer in a common pedicle with the main renal artery. It often turned in a cranial arc to the lower hilum.

Those supplementary arteries that originated more than 70 mm distal to the main renal artery had their origin in the aorta, middle sacral artery or iliac artery, which was always at a level distal to L III except in one case. These vessels represented persisting arteries which had arisen during the ascent of the kidney. In 13 of these 19 kidneys the vessels ran an extrahilar course. Whether further extra hilar vessels were present could not be decided because the examinations were made in one plane only, but in the remaining 6 kidneys the vessel was projected at the level of the lower part of the renal hilum. In 15 kidneys the vessels had an ascending course and in 5 the kidneys were malrotated. In a further 3 cases the kidneys were malrotated so that the hilum faced ventrally, but in none of them were any signs of cranio caudal dystopia, although the kidney was low and the supplementary arteries therefore almost horizontal. In all of these kidneys the ureter was of normal length. In addition to the 8 malrotated kidneys slight malrotation was also seen in 7 other kidneys as evidenced by the fact that the entire confluence of the renal pelvis was projected over the kidney. In these kidneys the vessels were also definitely straightened. In all of these the main renal artery originated at a normal level. Also within the 70 mm limit but close to it an intrarenal pelvis was occasionally seen but no true malrotation (Fig. 37).

During the ascent of the kidney the renal hilum turns from an originally ventral position to a medial one. Never during this period does the hilum appear to face laterally or dorsally. Formerly it was believed that the variation in the position of the hilum in adults was due to varying degrees of rotation of the kidney about its longitudinal axis (HAUCH 1903, GEMMILL 1935). PRIMAN (1929) however found no true rotation of the kidney but only an apparent rotation due to different regional growth of the renal parenchyma. He based his opinion on the investigations of FELIX (1911) who showed that the number of ventral tubular divisions was about twice as many as the dorsal. BROCKMAN (1936) did not find any true rotation but believed that the position of the renal hilum was due partly to the ureteric tree (which as an active component during embryonal life modified the renal tissue) and partly because of the surroundings of the kidney (which as a passive component influenced the position). LOFGREN (1949) showed that the position and above all the shape of the hilum depended upon changes in the arrangement or topography of the pyramids during embryonal life. YOUNG & THOMPSON (1903) described the vessels as being more common on the medial (i.e. dorsal) side of the kidney.

arteries was large they entered the renal hilum separately Only arteries to pyr 1 2 V D appeared to run an extrahilar course

Supplementary arteries arising more than 70 mm distal to the origin of the main renal artery or distal to the middle of L III represented persisting arteries arising during the ascent of the kidney Such arteries were seen in 19 kidneys 8 of which were clearly malrotated while 7 had a pelvis whose confluence was projected over the kidney suggesting a certain degree of malrotation i e incomplete rotation Of the entire clinical angiographic series these were the only malrotated kidneys situated at a normal level The ascending stretched artery to the lower pole in most of these cases ran an extrahilar course and prevented normal rotation of the kidneys This rotation is not due solely to differences between the growth of the ventral and dorsal pyramids as was formerly supposed but to a true rotation of the kidney about its longitudinal axis

SUMMARY

An investigation of the roentgen anatomy of multiple renal arteries was carried out in a clinical series examined by renal angiography consisting of a total of 369 patients of which 288 were examined by aortic angiography 81 by selective angiography In an autopsy series 34 kidneys were examined by a method described in Part I The findings may be summarized as follows

Frequency of multiple arteries — After exclusion of dystopic and fused kidneys there were 639 kidneys with multiple arteries in 23 8 % After kidneys with hydronephrosis due to obstruction at the uretero pelvic junction were excluded (64 kidneys with multiple arteries in 71 6 %) multiple arteries were found in 20 7 % This figure is about 10 % lower than that found in autopsy material and was due to the fact that small caliber arteries to the upper pole were not always demonstrable in the roentgenogram

Fields of supply topography and relative frequency of supplementary arteries — 142 kidneys with multiple arteries were studied with respect to field of supply and relative frequency of supplementary arteries Apart from their early origin and varying course to the kidney the supplementary arteries did not differ from segmental arteries to kidneys having a single renal artery (Part I)

Pyr 1 2 V D segment — Supplementary arteries to pyr 1 2 V D segment were found in 14 1 % of all kidneys with multiple arteries a figure about 10 % lower than found in autopsy material The reason for this discrepancy was explained by angiograms of autopsy specimens in 2 out of 5 specimens with supplementary arteries to pyr 1 2 V D the supplementary arteries were so narrow that they were not demonstrable in a clinical angiogram The artery

outline (Figs 26 28 30) However the examination should always be supplemented by aortic angiography if supplementary arteries are demonstrated or suspected in order to avoid missing any pathologic change in the part of the kidney that was not filled Since selective angiography is superior to aortic angiography it should be used routinely in the investigation of the kidney Aortic angiography is used only if there is reason to suspect that the kidney is supplied by more than one renal artery (hydronephrosis with obstruction at the uretero pelvic junction malrotation dystopic kidneys fused kidneys double kidneys) and if selective angiography fails

2) Supplementary arteries to the upper pole are often so small that they are not demonstrable in the roentgenogram It is important for the surgeon to be aware of this and to realize that even if the roentgenologist s report does not mention multiple arteries supplementary arteries to the upper pole might nevertheless be present These supplementary arteries to the upper pole are of less diagnostic significance because of the smallness of their fields of supply Supplementary arteries were not so small in caliber in any other segment of the kidney therefore this source of error is unimportant in the evaluation of the vasculature of the kidney as a whole

Since such multiple arteries to the upper pole are not always demonstrable in the angiogram the frequency of multiple arteries as shown in the clinical angiogram is somewhat lower than that found at autopsy

3) The field of supply of the supplementary arteries varies widely The variation was greatest for the supplementary dorsal artery which in one third of the cases supplied half of the kidney The most important vessel is the supplementary artery to pars inferior because this vessel occurs in clinical angiograms about twice as often as all other segmental arteries together and because of its surgical importance (hydronephrosis resection) In about 60 % of all kidneys the supplementary lower polar arteries supplied 25—50 % of the parenchyma It most frequently supplied the entire pars inferior which suggests as in the series with a single renal artery that there are often good possibilities of performing partial resection of this portion of the kidney

4) Supplementary arteries to the kidney are of two types persisting mesonephric arteries and persisting arteries to the metanephros developing before or during the ascent of the kidney

About 80 % of supplementary arteries supplying pars inferior arose cranial to the middle of L III and represented persisting mesonephric renal arteries The only way in which the latter vessels differed from segmental arteries of the renal artery was their abnormal origin The course of these vessels was the same as that of ordinary segmental arteries and they often ran in a common pedicle with the main artery However when the distance between the two

group The malrotation was ascribed to the supplementary artery, because its extrahilar dorsal branch prevented normal rotation of the kidney In addition to clear malrotation, some cases in this group showed an 'intrarenal' pelvis where the confluence was projected over the kidney, thereby indicating incomplete rotation Such an 'intrarenal' pelvis was also occasionally seen, when the supplementary artery arose proximal but close to the 70 mm level

supplied only a small portion of a pyramid in such cases When supplementary arteries to the upper pole were demonstrable in the angiogram they usually supplied two pyramids usually pyr 1–2 V, sometimes pyr 1–2 D seldom all 4 pyramids

Pyr 3–5 V segment — In 5 6 % of the kidneys supplementary arteries supplied this segment The field of supply of the vessel varied from 1 to 5 pyramids

Pyr 3 5 D segment — Supplementary arteries to this segment were observed in 14 1 % The field of supply of the vessel varied In two thirds of the kidneys it supplied 5 8 pyramids (35 55 % of the renal parenchyma)

Pyr 6 7 V D segment — Supplementary arteries were seen coursing to pars inferior in 72 5 % of the kidneys a figure somewhat higher than that found in studies in autopsies because the material contained an over representation of cases of hydronephrosis In 88 kidneys the field of supply of the artery was demonstrated In about half of these the vessel supplied the entire pars inferior and in nearly two thirds 25–50 % of the renal parenchyma The field of supply varied to a certain extent with the origin of the vessel from the aorta

Origin and course of supplementary arteries — While the ventral and dorsal supplementary arteries to the middle portion of the kidney originated from the aorta at a level close to that of the main renal artery either cranially or caudally and ran together with the renal artery in a common pedicle it was found that the supplementary polar arteries ran a separate course and branched at varying level from the main artery

R sup pyr (1) 2 V (D) regularly originated before the main artery at most 17 mm and usually ran directly to the segment without entering the sinus

R inf pyr (6–) 7 V D varied the most Its origin varied from 7 mm cranial to 135 mm caudal to the origin of the main artery In the majority of kidneys the vessel arose at a level very close to that of the main renal artery with which it ran a common course in the pedicle to the hilum where it continued as a normal segmental artery

The frequency of a supplementary artery to the lower pole decreased with increasing distance up to 70 mm distal to the main artery Distal to this level the frequency increased again with a maximum about 90 mm from the renal artery (Fig 33) The former group represented persisting mesonephric renal arteries while the latter consisted of arteries which had arisen during the ascent of the kidney While the vessels in the former group usually ran a descending or horizontal course or in a cranial convex curve and then entered the lower part of the hilum the majority of the latter ran an extrahilar course directly to the lower pole and appeared to be stretched All of the malrotated kidneys situated at normal level had a supplementary artery belonging to the latter

group The malrotation was ascribed to the supplementary artery, because its extrahilar dorsal branch prevented normal rotation of the kidney In addition to clear malrotation, some cases in this group showed an 'intrarenal' pelvis, where the confluence was projected over the kidney thereby indicating in complete rotation Such an 'intrarenal' pelvis was also occasionally seen, when the supplementary artery arose proximal but close to the 70 mm level

APPENDIX

VARIATION IN THE NUMBER OF RENAL ARTERIES WITH DIFFERENT TYPES OF RENAL PELVIS

The present investigation showed that the frequency of kidneys with multiple arteries was twice as high in the presence of changes at the uretero pelvic junction with hydronephrosis as in a normal series

Since aortic angiograms are preferable to selective if the kidney is supplied by more than one renal artery pre knowledge of any multiple arteries would reduce the number of cases first examined by selective angiography

While it is well known that malrotated, dystopic, and fused kidneys are almost always supplied by multiple arteries no investigations are on record of the frequency of multiple arteries in kidneys with normal variants of the renal pelvis (variation in number of calyces and outline of shape of pelvis) Since renal angiography is practically always preceded by urography, it would be useful if the latter examination could decide whether or not there was any reason to suspect the presence of multiple arteries, in a given type of renal pelvis

In kidneys with a double pelvis HELLSTROM (1927, 1928) found multiple arteries in 1 out of 6 SMITH RUSH & EVANS (1951) and SMITH (1953 1954) seldom found the kidney to be supplied by a single artery in the presence of a double pelvis and reported that the supplementary artery fed only a small part of the kidney

The anatomic variations in the shape of the renal pelvis (LEGUEU 1891, GRAUHAN 1932, HERMAN 1936, LOFGREN 1957 and others) as well as in the number of calyces (HAUCH 1903, LOFGREN 1949 and others) have been eluci dated LOFGREN (1957) homologized and restored the different types of renal pelvis to an antomically uniform basic type In the present investigation, however, use was made of the classification of the pelvis described by LEGUEU (1891) because the ampullar and ramified pelvis are widely used in roent genologic literature To these two were added an intermediary type and the double kidney pelvis

The type of renal pelvis in 413 kidneys with a single renal artery was com

Table 14 Multiple arteries in different types of renal pelvis

Type of renal pelvis	A single artery		Multiple arteries	
	Number	Per cent	Number	Per cent
Ramified	287	69 5	70	53 9
Intermediary	88	21 3	40	30 7
Ampullar	30	7 3	12	9 2
Double pelvis	8	1 9	8	6 2
	413		130	

pared to that in 130 kidneys with multiple arteries The results are given in Table 14

It is clear that the number of supplementary multiple arteries did not vary with the shape of the renal pelvis In 16 kidneys with double kidney pelvis, half were found to have multiple arteries, a higher frequency than normal The frequency thus lay between that given by HELLSTROM (1928) and that of SMITH, RUSH & EVANS (1951) and SMITH (1953, 1954)

As in SMITH s (1954) series, the present material contained no cases of double pelvis in which the supplementary artery supplied the entire primordial inferior lobe (pyr 4–7 VD) only pyramids in the pars inferior being supplied

The intrarenal vascular pattern is thus independent of the appearance of the ureteric tree This was also confirmed in the lobar division of the kidney (Part I) The two first pairs of pyramids formed one segment, and the third pair of pyramids, which also belonged to the superior primordial lobe, was included in the field of supply of the ventral and dorsal arteries together with the pars intermedia ventralis and dorsalis

The frequency of multiple arteries in relation to the number of calyces was studied in 207 kidneys with a single artery and in 64 with multiple arteries (Table 15)

Kidneys with a large number of calyces did not have multiple arteries more often than those with a small number A very large number of calyces suggest, that the kidney is supplied by a single artery (Table 15) This slight difference also coincides with that found in mammals (HYRTL 1872, CHIEWITZ 1897) in which multiple arteries are exceptionally rare and independent of whether the kidney is unipapillar (*e g* rabbit, horse) or has a large number of papillae (dolphin, bear) Investigations at the Roentgen diagnostic Department of the University Hospital Lund on kidneys of rat, dog and rabbit have also shown multiple arteries to be extremely rare This is also in agreement with the

Table 15 Frequency of multiple arteries in relation to number of calyces

Number of calyces	A single artery		Multiple arteries	
	Number	Per cent	Number	Per cent
3–4 calyces	6	2.9	0	0
5–6	35	16.9	9	16.7
7–8	100	48.3	29	53.7
9–10	52	25.1	15	27.8
11 or more calyces	14	6.8	1	1.8
	207		54	

findings of LOFGREN (1957), who showed that the different number of calyces depends on fusion of the papillae of the pyramids Multiple arteries are thus more common in man

CONCLUSIONS

The investigation showed no variation in the number of renal arteries in the different normal types of renal pelvis In these kidneys multiple arteries of diagnostic significance must be expected in about 20 % of all kidneys In kidneys with double pelvis or uretero pelvic obstruction, multiple arteries must be expected in about 50 % In these, as in all malrotated, dystopic, and fused kidneys aortic angiography should be performed

PART III

EXTRARENAL ARTERIES ARISING FROM THE RENAL ARTERY

INTRODUCTION

The renal artery and its branches supply not only the renal parenchyma but also the fatty capsule renal pelvis the upper part of the ureter as well as the adrenal gland These arteries are often visible in selective renal angiography Occasionally such vessels are also seen in aortic angiography but since vessels coursing to other abdominal organs are also filled and the density of the contrast medium in the perirenal vasculature is relatively low it is not possible to discern their pattern

The purpose of this part of the investigation was partly to chart the topography of vessels arising from the renal artery or its main branches and supplying the renal pelvis the upper part of the ureter and the fatty capsule and partly to elucidate changes in the pattern of these vessels in some common renal diseases

EARLIER INVESTIGATIONS

AUTOPSY STUDIES

Suprarenal arteries — The *inferior phrenic artery* as well as the *superior* and *middle suprarenal arteries* occasionally arise from the renal artery As a rule however of vessels to the adrenal only the *inferior suprarenal artery* comes from the renal artery and usually gives off a capsular artery which supplies the fatty capsule around the upper pole of the kidney (HYRTL 1872 SCHMERBER 1895 1896 PICK & ANSON 1940) LEVI (1909) and BUSCH (1954) found this vessel to originate from other vessels usually from the aorta in 25—30 per cent of their specimens

Capsular arteries — The *superior capsular artery* usually branches from the *inferior suprarenal artery* but occasionally directly from the renal artery HYRTL (1872) showed that when this artery arose directly from the renal artery it sometimes supplied a small region of parenchyma in the upper pole of the kidney

ANSON CAULDWELL PICK & BEATON (1947 1948) found that even when the vessels arose from the aorta small capsular arteries from the inferior

phrenic artery and the superior middle and inferior suprarenal arteries supplied small regions of parenchyma in the upper pole These findings were confirmed on angiography of kidneys removed *post mortem* (Part II) It was also observed that such arteries often escaped observation in aortic or selective renal angiograms because of their small caliber and minute field of supply

Middle capsular arteries — HYRTL (1872) observed vessels given off by the renal artery or its branches which he called *recurrent arteries* and *perforating arteries* because of their course in relation to the renal parenchyma SCHMERBER (1896) and others confirmed these findings The *recurrent arteries* arose from the dorsal and ventral branches of the renal artery in the hilum or sinus They first ran medially towards the hilar lip and then laterally towards the dorsal and ventral aspect of the kidney where they supplied the fatty capsule They were particularly abundant in the dorsal layer (SCHMERBER 1895) and anastomosed with other capsular arteries Similar vessels also supplied the sinus fat (AUGIER 1923)

The *perforating arteries* arose from interlobar or interlobular arteries penetrated the capsula propria supplied the fatty capsule and anastomosed with other capsular arteries These vessels were as a rule narrow and only scanty in adults (HYRTL 1872 SCHMERBER 1896) Other authors (DISSE 1902 AUGIER 1923) have found them to be abundant

The middle capsular arteries include also vessels arising from lumbar arteries mesenteric arteries and colic arteries Capsular arteries may also arise directly from the aorta though rarely

Inferior capsular artery — According to SCHMERBER (1895) the spermatic (ovarian) artery gives off a branch running to the fatty capsule at the level of the lower pole This capsular branch runs cranially along the lateral border of the kidney and anastomoses with other capsular arteries This branch forms the vessel known as *l arcade exorenale* (SCHMERBER 1895) along the lateral border of the kidney together with the superior capsular artery This extrarenal vascular arcade is of regular occurrence (Fig 42)

As a rule the *internal spermatic artery* is given off by the aorta though sometimes by the renal artery (GÉRARD 1913) or by supplementary renal arteries (ANSON & KURTH 1955)

Renal pelvic and ureteric arteries — Narrow arteries arising from the ventral and dorsal arteries supply the renal pelvis (HYRTL 1872 SCHMERBER 1895) DOUVILLE & HOLLINSHEAD (1955) found a large number of small branches extending to various levels of the renal pelvis These small vessels arose from the renal ventral and the dorsal arteries and their branches in the sinus and anastomosed with one another

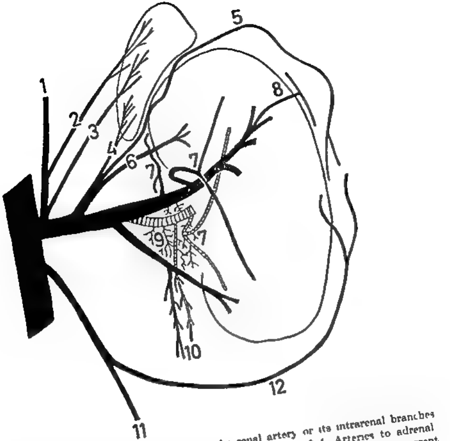


Fig 42 Diagram of arteries arising from the renal artery or its intrarenal branches and supplying extrarenal parts 1 Inferior phrenic artery 2 4 Arteries to adrenal 5 Superior capsular artery 6 Rt sup pyr 1 N 7 8 Middle capsular arteries Recurrent (7) and perforating (8) arteries 9 Pelvic arteries 10 Ureteric arteries (ventral and dorsal) 11 Internal spermatic artery 12 Inferior capsular artery which together with the superior capsular artery forms *l'arcade exorénale* (SCHMERBER) Occasionally though rarely the inferior capsular artery departs from the renal artery

The lower part of the confluence of the pelvis and the upper part of the ureter are supplied either by one artery which as a rule originates in the ventral artery, or by two arteries one arising from the ventral artery and one from the dorsal artery (HYRTL 1872 SCHMERBER 1895 ROBINSON 1902 SAMPSON 1904 and others)

In the presence of malignant tumours of the renal pelvis one would expect to find pathologic vessels originating in the pelvic or ureteric artery, but no such vessels have been observed in aortic angiograms (NELSON 1942, DOSS 1946, RUNSTROM 1948 PALMLOV 1952, W[illegible]DE 1952, LINDBLOM & SELDINGER 1955 EDSMAN 1957 and others) Pathologic vessels have, however, been seen in a selective angiogram of a case of cancer of the renal pelvis (PIRONTI & TARQUINI 1958) Whether the pelvic or ureteric arteries were involved is not stated At a symposium held in 1957 in Turin at which a large number of selective renal angiograms were shown BIONDETTI & MARANI pointed out that the ureteric artery could be demonstrated in such angiograms, but mentioned nothing about its appearance or diagnostic value in the investigation of renal disease

SCHIMATZEK (1958) described an accumulation of contrast medium in the wall of the renal pelvis as seen in an aortic renal angiography in a case of advanced chronic pyelonephritis and hydronephrosis, but no description was given of the pelvic or ureteric arteries

SUMMARY

The topography of the vessels supplying the renal fatty capsule, pelvis and ureter has been charted by autopsy and in corrosion preparations The appearance of these vessels in a few cases of selective renal angiograms has also been described, but no systematic investigations have been made of the appearance of these vessels in health and in disease

AUTHOR'S INVESTIGATIONS

MATERIAL AND METHODS

Seventeen pairs of kidneys together with the perirenal fat adrenals and aorta were removed *en bloc post mortem* The renal artery was ligated at its origin after which contrast medium was injected and angiograms were taken at different angles (see also Parts I and II) One of the kidneys was rejected because of leakage of contrast medium

The pattern of the arteries supplying the renal pelvis ureter and the fatty capsule was studied in 90 kidneys of living subjects examined by selective renal angiography The amount of contrast medium injected varied between 5 and 10 ml according to the size and function of the kidney The contrast medium used was Urografin 60 per cent occasionally Hypaque 45 per cent The injection pressure ranged between 2 5 and 3 kg/cm² In all of the examinations the density of the contrast medium in the renal artery was optimal The demonstration of extra renal vessels was not influenced by the amount of contrast medium injected

RESULTS

ANATOMIC STUDIES OF KIDNEYS FROM CADAVERS

Of the total of 33 specimens studied the *inferior phrenic artery* and the *superior+middle suprarenal arteries* arose from the renal artery in 3 and 5 specimens respectively The superior and middle suprarenal arteries often appeared as a bundle of thin vessels with a characteristic straight craniolateral course (Figs 43 and 44)

In 15 of 33 kidneys a vessel was seen to arise from the renal artery or one of its branches In 8 of these cases the vessel stemmed directly from the renal artery in 4 from a primary branch of it and in 3 from a supplementary artery to the pyr 1 2 V D segment This vessel branched and ran partly to the lower part of the adrenal as the *inferior suprarenal artery* and partly adjacent to the upper renal pole after which it ran a tortuous caudal course along the

a *b*

Fig. 44. Autopsy specimen (right kidney). *a* True frontal view. *b* True size reproduction of part of angiogram illustrated in *a*. Observe the characteristic course of the superior capsular artery (⟶) along the lateral border of the kidney. The artery, which departs from a supplementary artery to the upper pole (⟶), divides into two branches of roughly equal caliber. Narrow suprarenal arteries also stem from the supplementary artery. Ureteric arteries (⟶) stem from the lower polar artery and the dorsal artery. Graceful vessels are seen supplying the pelvis (*b*).

these kidneys the artery divided into 2 branches of equal caliber (Fig. 44): one to pyr[illegible] and the other to the fatty capsule.

In 13 of 33 kidneys no arteries were seen to run to the adrenal or upper part of the renal fatty capsule.

In all of the kidneys except one, narrow arterial branches were seen to run dorsally and/or ventrally to the intermediate part of the kidney — *middle capsular arteries*. These arteries departed either from the renal artery or its main branches, most frequently from the dorsal artery or sometimes from other capsular arteries. When the vessels arose in the sinus they first ran

Fig 45 Autopsy specimen (left kidney) A recurrent artery (→) branches from the dorsal artery in the sinus Middle capsular arteries running caudally and cranially are seen medial to the hilum Ureteric artery (|→) departs from lower polar artery

medially to the level of the hilar lip and then it turned in a lateral direction giving off branches extending cranially and caudally (recurrent arteries HYRTL 1872) (Fig 45)

Perforating arteries (HYRTL 1872) were observed in only a few kidneys (Fig 46) With the technique used it was not possible to detect the origin of these vessels

In 2 kidneys a filling was obtained of the *internal spermatic artery* which branched from a supplementary upper polar artery in one specimen and from a supplementary lower polar artery in the other

In 7 kidneys a filling of the *inferior capsular artery* was obtained but only in one of them was the vessel well developed (Fig 47) and in that specimen the superior capsular artery was narrow and short The vessel departed from the lower polar artery in 2 kidneys from a supplementary upper polar artery in 1 from the dorsal artery in 1 and from other capsular arteries in 3

In all of the kidneys except one (in which the contrast medium was so viscous that no filling was obtained of the interlobular arteries) numerous narrow (about 0 1—0 2 mm caliber) arteries were seen to run from the

a

F g 4(A t j v ą] ■ m   l ft k lney) V ew o re t   l g   fr ntal a l h que f ntal b) True I roj t ns a t repr l et n f part of a g gran n a Il e n ld le ap« ar art r e (   ) tem fro the dorsal ar tery an l e]] ly the fatty capsul l rsal to tl e k i ney An u comm nlv w l perforating artery (⟶) ar ses from an nterlobar arter n tl e lower pol The ureter e artery (⟶) branches from tl e lower polar artery Pelv c arte r es are seen in c

Fig 47 Autopsy specimen (right kidney) Superior and inferior capsular arteries stem from a supplementary artery to the upper pole and form *l arcade exorénale*

renal artery and its primary branches (Figs 43 44, 46) These *pelvic arteries* formed a fine network around the renal pelvis within the region of the confluence The vascular network could not be recognized peripherally because of the accumulation of contrast medium in the parenchyma

In 30 of 33 kidneys the angiograms showed a narrow artery that was wider than the pelvic arteries but narrower than the middle capsular arteries and coursed to the upper part of the ureter as the *ureteric artery* As a rule this artery arose from the lower polar artery but sometimes came from the renal

artery or one of its primary branches (Figs 43 45 46) Some kidneys had a dorsal and a ventral ureteric artery (Fig 44) The non visualization of the ureteric artery in the remaining kidneys was due to the contrast medium being viscous in 1 and not being injected into a supplementary lower polar artery in 2

The middle capsular arteries the pelvic arteries and the ureteric artery were thus regularly seen In about half of the specimens the inferior suprarenal artery and the superior capsular artery were demonstrable Only occasionally could the inferior phrenic artery superior+middle suprarenal arteries inferior capsular artery and spermatic artery be identified

ANATOMIC STUDIES OF SELECTIVE RENAL ANGIOGRAMS

Selective angiograms of 90 kidneys were studied for the occurrence of extrarenal arteries arising from the renal artery Arteries of one or more of the above mentioned types were found in 65 of the 90 kidneys studied It was noteworthy that the contrast medium persisted longer in these vessels than in any of the vessels in the kidney Extra renal vessels could therefore be readily distinguished from intra renal branches (Fig 48)

Inferior phrenic and superior and middle suprarenal arteries were observed in only 1 kidney The arteries arose from the renal artery close to its origin from the aorta

Inferior suprarenal artery and/or superior capsular artery were demonstrated in 30 kidneys (one third of the cases) usually both When the tip of the catheter was located medial to the origin of the artery from the renal artery a filling was obtained of the capsular arteries and suprarenal arteries as well as an accumulation of contrast medium in a part of the adrenal (Fig 49) When the tip of the catheter was situated peripherally to the origin of the suprarenal and capsular arteries a filling was obtained of these vessels though the contrast density was much lower and as a rule no filling was obtained of the adrenal The superior capsular artery had a characteristic course running tortuously in a caudal direction along the lateral border of the kidney often far out laterally in the fatty tissue (Fig 50)

In [illegible] cases the capsular artery departed from the artery supplying pyr 1 2 V D (Fig 48)

Middle capsular arteries were observed in 36 out of 90 kidneys The vessels arose from the dorsal artery and sometimes from the ventral and renal arteries (Figs 50 and 55) Since the capsular arteries did not appear until in the late arterial phase their origin in the sinus could not always be recognized because of commencing accumulation of the contrast medium in the parenchyma

[illegible] *Bo ten*

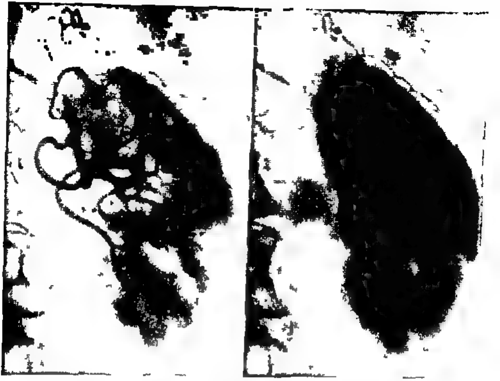


Fig 48 Selective renal angiogram (left kidney) The peripheral part of the superior capsular artery is still demonstrable in the nephrogram

For the same reason it was usually not possible to follow the course of the vessels on the dorsal or ventral aspects of the kidney The middle capsular arteries were therefore observed mainly medial to the renal hilum as narrow vessels with twigs running cranially as well as caudally

Perforating arteries were seen in a few small kidneys with a narrow renal artery

Only in 2 angiograms was a filling obtained of the *inferior capsular artery* and in none was the *internal spermatic (ovarian) artery* demonstrable

The fine network of the *pelvic arteries* seen at the site of the confluence of the pelvis in angiograms of kidneys from cadavers was never visible in selective angiograms On the other hand, a faint accumulation of contrast medium was seen in the wall of the renal pelvis in 2 kidneys

In 27 of 90 kidneys one or more arteries were seen running to the lower part of the pelvic confluence and the upper part of the ureter (*ureteric arteries*)

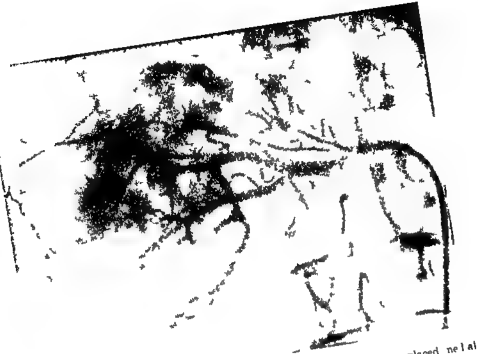


Fig. 49. Selective renal angiogram, right kidney. Tip of the catheter is placed ne l al to the origin of superior capsular artery and inferior suprarenal artery. Accumulation of contrast in adrenal. Superior capsular artery is displaced by solitary cyst in the lateral and lower part of the kidney.

As in the examination of the post mortem specimens the artery was usually found to depart from the lower polar artery and occasionally from other branches of the renal artery. As a rule the vessel was narrow, but in 13 it was wider than might be expected from the apperance of the ureteric artery in angiograms of post mortem specimens.

Only in a few angiograms were the capsular arteries, renal pelvic arteries and the ureteric arteries demonstrable at the same time. Since only the superior capsular artery and the inferior suprarenal artery arose early, demonstration of the other arteries was not dependant on the position of the tip of the catheter.

Fig 50a Solitary cyst in the central part of left kidney and chronic pyelonephritis Selective renal angiogram in early arterial phase Proximal parts of suprarenal (⟶) and superior capsular arteries (|⟶) are seen as well as unusually wide ureteric artery (>⟶)

ANGIOGRAPHIC APPEARANCE OF CAPSULAR AND RENAL PELVIC ARTERIES IN SOME PATHOLOGIC CONDITIONS

In order to find out whether the appearance of the arteries in selective renal angiograms might be of any diagnostic value the appearance of these vessels was studied against the background of the clinical diagnosis or the pathologic diagnosis when available

Fig 50b Late arterial phase Superior capsular artery (←→) has a winding course far out in the perirenal fatty tissue but is not displaced by the cyst Middle capsular arteries (←→) are seen medial to hilum

Chronic pyelonephritis — In 21 of 27 kidneys of chronic pyelonephritis extra renal vessels were seen to extend into surrounding tissues

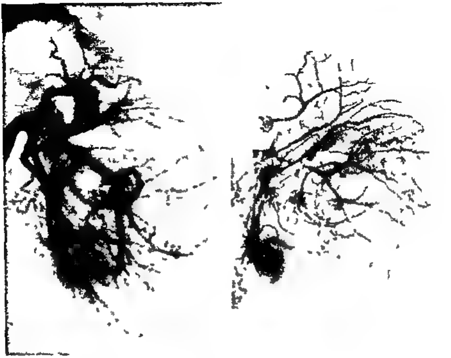
The middle and superior capsular arteries were of normal width and observed with the same frequency as in the entire material In 8 kidneys a filling was obtained of the ureteric artery and in 3 of these it was wider than usual (Fig 50) The frequency with which the ureteric artery was demonstrable in

Fig 51 Selective renal angiogram (left kidney) Superior capsular artery (→) ureteric artery (→) and intrarenal arteries are displaced by a large renal carcinoma

this series was the same as that in the material as a whole (about 30 per cent)

Renal carcinoma — In 4 of 9 kidneys of renal carcinoma the superior capsular artery was demonstrated and found to be of normal width In renal

a



b

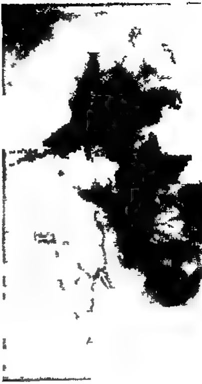
Fig 52 Renal carcinoma centrally in left kidney *a* Selective renal angiogram *b* Arteriogram of operative specimen Ureteric artery (→) is wide and supplies the tumour

carcinoma the capsular artery may be displaced to a varying extent depending on the size and position of the tumour (Fig 51) In 3 kidneys the middle capsular arteries were demonstrated all were wider than normal and all appeared to supply the tumour In 5 kidneys the ureteric artery was also outlined and in [illegible] it was wider than normal (Fig 52) In 2 of the cases no vessels to surrounding tissues were observed

Renal tuberculosis — Perirenal vessels were seen in all 5 kidneys of renal tuberculosis studied In 3 the middle capsular arteries and the ureteric arteries were wider than usual In one an accumulation of contrast medium was seen in the pelvic wall and the upper part of the ureter (Fig 53) Histologic examination in this case showed pronounced tuberculous inflammation of the wall of the renal pelvis

Cancer of the renal pelvis — In 2 of 3 kidneys of cancer of the renal pelvis

a



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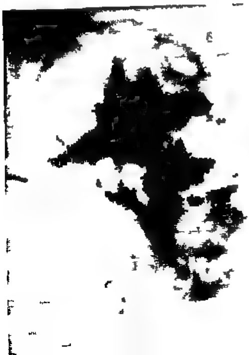

F g 53 Tuberculos s of left k dney Select ve renal ang ogram *a* Ar er al pl ase *b* Early nephrograpl c pha e ■ Late nephrograpl c pl ase M l lle cap lar arter es (⟶) and w le ure ter c artery (⟶) are seen A cumula t on of contrast me l m n confluence and pper part of u eter Tl e wa l of tl e pel is of the operat e spec men and tl e ureter were th ck an l showed m n an l gra

the tumour had caused considerable hydronephrosis In both cases the renal artery was narrower than normally so that the supply to the kidney was considerably reduced Pathologic vessels branching from intra renal arteries were observed in the region of the tumour and in both cases a wide ureteric artery extended from the lower polar artery and also supplied the tumour with pathologic vessels (Fig 54) The diagnoses were papillary and anaplastic cancer of the renal pelvis respectively

In the third kidney there was a small papillary renal pelvic cancer of the ramus to the upper calyx No pathologic vessels were seen

Hydronephrosis — 4 of 11 kidneys of hydronephrosis studied showed middle capsular arteries displaced by the dilated confluence (Fig 55) Only in 3 were ureteric arteries seen and in 2 they appeared to be wider than normal In the third the ureteric artery was not dilated but there was an accumulation of contrast medium in the wall of the renal pelvis and early filling of the pelvic veins (Fig 56)

In some other cases of renal disease capsular arteries were demonstrated but were not dilated In a further 6 kidneys ureteric arteries were also de monstrated but in none were they dilated

DISCUSSION AND CONCLUSIONS

It is obviously easier to demonstrate the occurrence of vessels in angiograms of autopsy specimens than in selective angiograms As a rule clinical angio graphy with ordinary contrast medium will not outline vessels less than 0 3 mm in diameter (MATTSSON 1955)

In an attempt to form an opinion as to how often selective angiography will show arteries arising from the renal artery (or the main artery in the presence of multiple arteries) to surrounding tissue selective angiograms were compared with the angiograms of kidneys from cadavers (Table 10)

The *inferior phrenic superior suprarenal middle suprarenal* and the *inferior capsular arteries* seldom originated and the *internal spermatic artery* never took origin from the renal artery Since it is usually the internal spermatic artery that gives off the inferior capsular artery it is obvious that it was not possible to demonstrate SCHWERBER s (1895) *arcade exorenale* in the clinical angiograms When arteries to the upper and intermediate part of the adrenal and the inferior phrenic artery arise from the renal artery they do so quite close to the aorta so that they are rarely demonstrable in selective angiograms Aortic angiography appears to be preferable in the investigation of adrenal tumours because of the better prospects of obtaining a filling of the adrenals

The frequency with which the *superior capsular artery* and the *inferior*

F g 54 t Fist s zed mal gnant pap lloma of tl e pelvis (r ght k lney) Tl e ki l ey was

suprarenal artery were demonstrable was 6 % lower in selective angiograms than in angiograms of specimens removed *post mortem* This difference may also be explained by the origin of the ioned arteries to the aorta

The width of the superior capsular d considere field of supply Sometimes the vessel ext to the level

Fig 24b Nephrographic phase The pelvic tumour is supplied by pathologic vessels from intrarenal arteries and from the wide ureteric artery

renal pole and was then narrow but sometimes it continued to the fatty tissue at the lower pole and was then wider

The course along the lateral border of the kidney was characteristically tortuous and the superior capsular artery sometimes extended far out into the perirenal fat without necessarily being displaced In the presence of a space occupying tumour the vessel was displaced to an extent varying with the size and position of the tumour In none of these cases did the superior capsular artery appear to be dilated In selective angiograms performed after this

Fig 54a Fi t sized malignant papilloma of the pelvis (right kidney) The kidney was enlarged and the parenchyma was severely reduced Selective renal angiogram Arterial phase Intrarenal arteries are reduced in width and displaced A middle capsular artery (⟶) is displaced Ureteric artery (⟶) is displaced and wide

suprarenal artery were demonstrable was 6 % lower in selective angiograms than in angiograms of specimens removed *post mortem* This difference may also be explained by the origin of the above mentioned arteries being close to the aorta

The width of the superior capsular artery varied considerably with its field of supply Sometimes the vessel extended only to the level of the upper

Fig. 54b. Nephrographic phase. [illegible] tumour [illegible] supplied by pathologic vessels from intrarenal arteries and from the [illegible] artery

renal pole and was then narrow, but sometimes it continued to the fatty tissue at the lower pole and was then wider.

The course along the lateral border of the kidney was characteristically tortuous and the superior capsular artery sometimes extended far out into the perirenal fat without necessarily being displaced. In the presence of a space occupying tumour the vessel was displaced to an extent varying with the size and position of the tumour. In none of these cases did the superior capsular artery appear to be dilated. In selective angiograms performed after this

Fig. 55. Hydronephrosis (right kidney). *a* Selective renal angiogram. Middle capsular arteries (⟶) are displaced by the dilated confluence. *b* Retrograde pyelogram.

examination was finished, definitely dilated superior capsular arteries supplying renal carcinoma were seen.

As in the series of ANSON, CAULDWELL, PICK & BEATON (1948) the capsular artery was found to run to the upper renal pole together with a supplementary polar artery (Part II). In cases with a single renal artery the superior capsular artery sometimes arose from the artery to the pyr. 1 + 2 V.D. segment. In all of these cases and in contradistinction to that found when the vessels left the aorta together, the capsular artery was narrower than the segmental artery.

The vessels running to the perirenal fat on the ventral and dorsal aspects of the kidney were called *middle capsular arteries*. In the post mortem angiograms the vessels could be followed throughout their course, while in the selective angiograms they could, as a rule, be identified only medial to the hilum because the filling of the rest of their course was masked by the early nephrographic phase. Partly for this reason and partly because the ureteric

Table 16 : Frequency of extrarenal arteries arising from renal artery and demonstrated in angiograms of

	Kidneys removed post mortem (total 33 kidneys)	Kidneys in living beings (total 90 kidneys)
A phrenica inf	6 %	1 %
A supraren sup and media	9 %	1 %
A supraren inf and capsularis sup	39 %	33 %
Aa capsulares mediae	91 %	40 %
Aa nutrientiae pelvis	97 %	0 %
A ureterica	82 %	30 %
A spermatica int	0 %	0 %
A capsularis inf	6 %	2 %

artery was often similar in course and appearance the middle capsular arteries could only be distinguished with difficulty from the ureteric artery The latter ran caudo medially and could be followed further distally than the capsular artery The ureteric artery often stemmed from the lower polar artery, while the capsular artery branched more proximally from the renal artery or one of its branches and also gave off branches running in cranial direction They often appeared to anastomose

In the angiograms of the kidneys from cadavers a filling of the middle capsular arteries from the renal artery was nearly always demonstrable, while in the selective angiograms they were seen in only 40 % because of their small size and close relationship to the renal parenchyma

In 5 angiograms the vessels appeared to be wider than usual namely in 3 with renal carcinoma and 2 with tuberculosis

The vessels were often displaced by hydronephrosis or tumour and the degree of displacement provided a rough measure of the degree of dilatation of the pelvis or size of the tumour

Pelvic arteries — In almost all of the angiograms taken at autopsy an extrarenal fine network of pelvic vessels was seen around the confluence of the pelvis The vessels were so delicate that they could not be demonstrated in selective angiograms

In 2 kidneys hypervascularity was demonstrated by a faint accumulation of contrast medium in the wall of the renal pelvis

Of the kidneys removed *post mortem* *ureteric arteries* were seen to extend

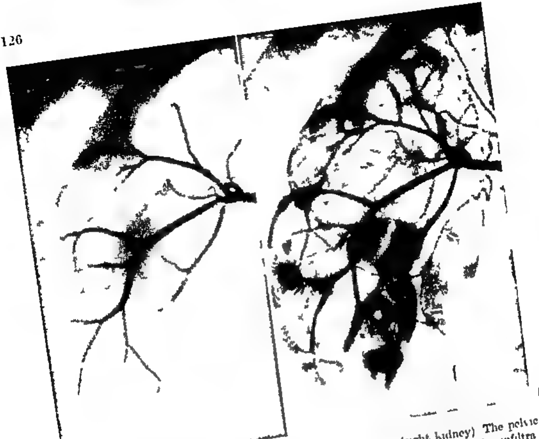

Fig 56 Hydronephrosis with severely reduced parenchyma (right kidney) The pelvic wall of the operative specimen was oedematous and showed advanced cellular infiltration Selective renal angiogram

a Early arterial phase *b* Middle arterial phase Ureteric artery (→) is thin and displaced by dilated confluence as in one of the middle capsular arteries (›→) Accumulation of contrast medium in pelvic wall

from the lower polar artery or other branches of the renal artery in 82 % of the kidneys but in only 30 % of the selective renal angiograms This difference was due to the fact that the artery was often so narrow that it was doubtful whether it would normally ever be apparent in the angiogram (Fig 46) In 13 of the 27 kidneys in which the artery was observed it was definitely wider than normal because it had been involved by tumour or inflammatory process in the kidney It is considered that in the remaining cases in which the vessel was demonstrated it had probably been widened by such a pathologic process but it could not be classified as definitely enlarged

Fig. 36c Late arterial phase Pelvic veins (←→) are filled early

A ureteric artery could be identified in only 3 of 11 kidneys with hydronephrosis (6 with co-existant infection of the kidney) This low frequency was due possibly to diminished vascularisation of the kidney which is common in hydronephrosis

The hydronephrosis group did not include the 2 kidneys in which the dilatation was due to cancer of the renal pelvis In these the parenchyma was markedly reduced and therefore the nephrogram was less dense and did not mask the pathologic vessels in the pelvic tumour In both the ureteric artery was widened and supplied the tumour and pathologic vessels were seen In the third case with a small papillary cancer of the renal pelvis the angiogram showed no pathologic vessels

Selective renal angiography has considerably increased the possibilities of diagnosing cancer of the renal pelvis because it is possible to obtain optimal

filling of the arterial tree with accumulation of contrast medium in the tumour especially if the renal parenchyma is markedly reduced If the ureteric artery supplies the tumour the artery will be wider than usual and in its field of supply there will be pathologic vessels A small intrarenal cancer of the pelvis can not be detected by angiography however because in such a case the tumour is supplied only by the thin arteries in the renal sinus which are too fine to be identified The accumulation of the contrast medium in the normal renal parenchyma will mask any pathologic accumulation in such a tumour

SUMMARY

Angiographic studies of the topography of extrarenal arteries arising from the renal artery or its branches or from supplementary arteries were performed in 33 kidneys removed *post mortem* and the results compared with selective renal angiography in 90 kidneys

Owing to their early origin from the renal artery the *inferior phrenic artery superior suprarenal artery middle suprarenal artery* and to a certain extent the *inferior suprarenal artery* and the *superior capsular artery* will be seen in the selective angiography less frequently than might be expected from examinations in the *post mortem* specimens Aortic angiography should therefore be given preference in the investigation of suspected space occupying tumours involving the adrenals

The density of the contrast of the inferior suprarenal artery and the superior capsular artery but not the other adnexal arteries varies with the position of the tip of the catheter If the contrast density in the inferior suprarenal artery is high part of the adrenal will be outlined

The field of supply and thereby the width of the superior capsular artery varies considerably The vessel runs a tortuous course along the lateral border of the kidney The artery is liable to be displaced by space occupying lesion

The *middle capsular arteries* may be displaced by expanding tumours In *hydronephrosis the size of the extrarenal part of the renal pelvis* can be judged from the degree of displacement of the capsular arteries The vessels may be dilated in the presence of space occupying and inflammatory processes

In pronounced chronic pyelonephritis any hypervascularity will be seen in the renal angiogram as an accumulation *of contrast medium in the* wall of the renal pelvis The *renal pelvic arteries* are so narrow that they do not show up in the angiogram

The *ureteric artery* may be dilated under certain circumstances such as in chronic pyelonephritis renal carcinoma cancer of the renal pelvis and tuberculosis It appears that it is only visible in the angiogram in such cases

The ureteric artery may supply a malignant tumour of the renal pelvis which will appear in the angiogram as pathologic vessels. Because of reduced vascularisation in the kidney the nephrogram will be less dense and pathologic vessels arising from intrarenal arteries can be demonstrated. If the tumour is small and intrarenal, no such pathologic vessels are seen because they will be masked by the accumulation of contrast medium in the parenchyma.

The investigation showed that if the amount of contrast medium is adjusted according to the size and function of the kidney as judged by urography arteries to the fatty capsule and to the renal pelvis will appear independent of the caliber of the renal artery and the position of the tip of the catheter.

GENERAL SUMMARY

Utilization of recent advances in renal angiography requires better knowledge of the normal angiographic pattern of the kidney. Pre operative angiography is an important guide in contemplated resection of the kidney. In such cases detailed information on the extent of the pathologic lesion and the topography of the intrarenal vasculature is indispensable. This prompted the present investigation the purpose of which was to analyze the roentgen anatomy of the vasculature of the kidney as seen in selective and aortic renal angiograms of living human beings and of post mortem specimens.

The investigation consists of three parts.

Part I deals with the angiographic pattern of the single renal artery. The results are summarized on page 52.

Part II is concerned with the frequency and angiographic pattern of multiple arteries. The results are summarized on page 97.

Part III is a study of extrarenal arteries arising from the renal artery. The results are summarized on page 128.

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